PRODUCT LIFECYCLE MANAGEMENT

Virtual Product Lifecycles for Green Products and Services

Proceedings of the PLM11 conference held at the Eindhoven University of Technology, The Netherlands, 11-13 July 2011

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Published by IFIP Working Group 5.1 on Global Product Development for the whole Lifecycle.

Co-publisher Maj Engineering Publishing, www.maj-engineeringpublishing.net

ISBN 978 90 79182 26 8 (print)

ISBN 978 90 79182 27 5 (online)

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Published by IFIP Working Group 5.1 on Global Product Development for the whole Lifecycle (www.ifip-wg51.org).

The full contents of this book can be accessed at www.ifip-wg51.org. Individual papers can bee downloaded free in pdf.

This book can be ordered in print at www.ifip-wg51.org or via info@maj-engineeringpublishing.net.

ISBN 978 90 79182 27 5 (online)

ISBN 978 90 79182 26 8 (print)

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Editorial

This volume contains the proceedings of PLM11, the 8th International Conference on Product Lifecycle Management. Product Lifecycle Management (PLM) originated in the late 1980's as a software tool to organize product data and improve engineering efficiency. Today it has evolved into "an IT driven business approach towards increased societal performance of products, taking all their lifecycle phases, from conception to disposal, into account". In fact PLM has evolved from a simple business opportunity for software vendors to a driver for radical change in the industry business model.

In the past century the development of new products was driven by technological possibilities and perceived needs in a general market. The goal was to sell the product with a profit and what happened after that was not really an issue for the manufacturer. Societal effects of products like pollution, waste of resources, public health and even customer satisfaction were hardly taken in account in the design of the product.

Now PLM promises to enable to design new products for optimal societal benefits over their whole lifecycle. This promise is inspired by the availability of cheap computing power that can be integrated in any product or service system, and by the emergence of wideband mobile communication systems that can exchange almost unlimited amounts of information between any two places on the globe. This brings the possibility to monitor the behavior of a product during its whole life, regardless the place where it is used. It also enables to involve many more stakeholders, as involved in the behavior of the future product during its life, in the design process. The ideal of PLM is a global industrial system that brings products with more life cycle value for the customer at less societal and environmental cost. In other words PLM promises sustainable economic growth with products that bring more wellbeing to the society.

PLM builds on Information Technology but it is about knowledge. PLM uses ICT to connect the people involved in the product life cycle, in order to share their knowledge and thus incorporate more knowledge, not only in the design, but in all life cycle processes. More knowledge means more efficient and more effective processes so more use for less cost.

The science in PLM is, amongst others, the science and technology of understanding and controlling the flow of knowledge around product lifecycles and to develop methods to intensify and speed up this flow: more knowledge must flow faster from invention to operation.

PLM11 is the 8th in a series of International Product Lifecycle Management Conferences, organized to bring together the international scientific PLM community. It also is the first to be organized under the umbrella of International Federation of Information Processing (IFIP) Working Group 5.1., giving the PLM research area a solid place in the community of Information Processing scientists. The structure of the conference program, expressed in the chapters of this proceedings, reflects the way science is occupied with PLM:

1. **PLM Processes:** PLM brings new processes in product development and management. These processes must be identified, analyzed, understood and improved,

2. **PLM implementation:** the possibilities of PLM go far beyond the current perception of most product development organizations. Therefor implementing PLM is about organizational change,
3. **Sustainability:** the specific knowledge that makes products more sustainable is identified and integrated in design processes,
4. **Collaboration:** the role of knowledge in collaboration must be better understood and knowledge must be better structured to be able to present proper knowledge at the proper place,
5. **Data management and traceability:** the amounts of data needed to capture knowledge about the whole life cycle will be huge. Also data is generated at different locations and by different parties. Better understanding of structuring principles and tools, to help users store data in the proper structure, are needed,
6. **Product Lifecycle:** designing for the product lifecycle requires better understanding of that lifecycle and its processes. It also requires new product modeling techniques to specify lifecycle properties of the product,
7. **Knowledge Management:** there is a challenge in integrating data management and knowledge management methods. A strong theoretic platform is needed to manage the complexity of product lifecycle knowledge,
8. **Semantics:** integrating data and knowledge from different disciplines, companies and cultures requires better understanding of semantics to detect and bridge the often subtle differences in meaning of data elements,
9. **PLM Maturity:** implementing the full PLM approach is a matter of many years of continuous improvement. PLM maturity is a means to position, compare and guide companies on their road to full PLM,
10. **Education:** the speed of realizing PLM in industry depends strongly on the education and training in PLM issues especially since training new staff is easier than changing old habits.

The organizers have chosen for open publishing of the PLM11 proceedings, so all papers are freely accessible on the internet. They believe that the main interest for the authors in particular and science in general is that papers are read and referenced, and therefore must be easily and freely accessible. Traditional scientific publishers had a task in creating and maintaining distribution channels. That takes much effort and it is reasonable to let the reader pay for that. Today internet provides a free distribution channel with easy retrieval of scientific papers so charging readers for downloading copies is not in the interest of the author. However, many scientists, or even more those who fund them, still weigh the score of a paper with the reputation of the publisher. So the discussion on open publishing is not closed in WG5.1. At the point in time where the PLM conference moves under the IFIP umbrella and has to change publisher consequently, it may be good as an experiment to have open publishing by IFIP WG5.1 itself.

For those who appreciate to have a physical book, there remains the possibility to order a paper copy via the normal publishing channels. We are grateful to Mai-Engineering Publishing for giving us access to the required logistic services.

Henk Jan Pels,
1st editor, June 2013.

Chapter 1
PLM Process

PLM as a Lever for Innovation

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Abstract: Innovative products and services are the key success factors for companies within the manufacturing industry. In industry practice time, cost and quality are generally the main drivers for product development departments. They also determine the engineering environment comprised of organizational measures, business processes, methods, and supporting IT systems. Innovation seems to be left the role of an appreciated side-effect. This paper investigates how an engineering environment should be designed in order to foster innovation. Product Lifecycle Management (PLM) is a concept often promoted for product development to address both time/cost/quality and innovation. This paper gives advice on how PLM is to be understood and set up to achieve this with best possible results – to exploit it as a lever for innovation.

Information modeling is identified as one key factor in this context; hence as one important means to foster innovation through PLM, an Enterprise Architecture Product Information Model is introduced.

Keywords: Engineering environment, PLM, innovation, information modeling

1 INTRODUCTION

During the economic crises one key differentiator of high performer companies is the ability to focus on new products or services in their R&D projects [1]. The so-called "magic triangle" of time, costs and quality often sets the predominant targets – successful engineering is measured by on-time, on-budget delivery to set quality goals. Thus time, costs and quality are the main focus of the business process models applied, the methods used and the supporting IT tools implemented. Together with the engineering organization these processes, methods and IT tools are the components which build the engineering environment, in which engineering work is executed [2].

Product Lifecycle Management (PLM) is a concept often promoted for product development to address innovation. Definitions of PLM range from a pure IT systems to a wide strategic and philosophical view. The broader this view, the broader are also the goals associated with the implementation or promotion of "PLM".

In the following chapters we will investigate how an engineering environment should be designed in order to foster innovation in parallel to the triangle goals. The investigation will be based upon empirical studies from engineering consultancy as well as from leading engineering organizations. The main research questions in this context are:

- *What approaches within the dimensions may promise positive effects on innovation?*

- *What should the interplay between the building blocks of organization, processes, methods and IT be like to foster innovation?*
- *Looking at current PLM solutions and the way these solutions are interacting with the organization and processes today – what are the requirements/boundaries for a product information management approach to support the increasing amount and various types of information across the entire enterprise and along the product lifecycle?*

The outline of this article is as follows. First, we will describe state-of-the-art components of engineering environments with PLM being given a special emphasis. Second, we will present the challenges and insights derived from empirical studies and consulting projects which focused on setting up innovative engineering environments. Third, we will introduce an approach to reflect product data based on the described environment. Then, in the discussion, we will address the interplay between the components of the engineering environment as well as the question, to what extent PLM could be a lever for innovation. Finally, we will conclude by revisiting the research questions and providing an outlook for future research. This paper builds on research work initially presented on ICED 2011 [3], and focuses on conclusions regarding information modeling, formalized in the Enterprise Architecture Product Information Model described in chapter 4.

2 ENGINEERING ENVIRONMENTS

Observations and leading practices suggest structuring the engineering environment into four main dimensions: Organization, processes, methods and IT [4]. The ratio and order in which these dimensions are addressed vary widely; their interrelationships will be discussed later. Product Lifecycle Management (PLM) is a strategic management concept for managing products along with their data and has its roots in product engineering and design. However, no commonly agreed definition of PLM exists. PLM concepts are often also structured according to the four dimensions of figure 1. Therefore, this paper will discuss the engineering environment with a special focus on supporting engineering and design work with PLM, and how PLM has to be understood against this background.

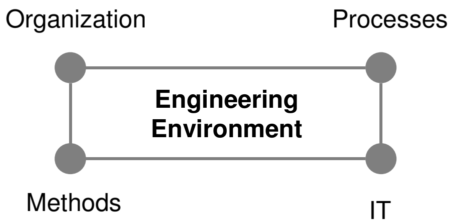

Figure 1 Dimensions of the engineering environment [3]

2.1 Organization

Engineering organization can be understood either in the state engineering is setup regarding processes and structure or in the way towards that state. Both understandings set the ground for the engineering environment to perform and possibly innovate. Within a product development project the timing and impact of management attention and influence varies and is often not aligned. As described in [5] the curve of "possible impact" (of management) is high in the very early project phases and declines in the later phases. The curve of "effective management impact" is low during the early project phases and reaches two peaks in the later phases – test, implementation and use. To profit from the "possible impact" in the early phases of a project and to optimize the "effective management impact" at the same time requires the appropriate organizational and procedural preconditions to be established. For this, relevant product information needs to be available through the product lifecycle and across department boundaries, thereby bridging the levels of hierarchy within an organization.

2.2 Processes & Methods

Independent of the industry and the type of product a company is selling; processes represent a core competency of any company. An effective and efficient management of business processes is a key success factor not only on a general business level but also for design departments within the design environment.

Beside the involvement of the company's management in the product development process, the utilization and the support of all employees involved in later phases of the product lifecycle are key factors for a successful product innovation process. These two dimensions of information flow are described in [5] as vertical and horizontal axes within the concept of PLM. In industrial practice the horizontal axis within the PLM solutions is well addressed. Depending on the maturity level of the implemented solution the focus of PLM activities is located around the design departments. On the other side, the vertical axis is currently not as well established. Especially the breakdown of strategic top management information is rarely defined and implemented. Experiences from different companies show that often neither processes nor organizational structures for the aggregation of information – from the lower level of the hierarchy to the higher levels – are in place.

Methods fill, support and solidify the respective process steps of the product development process. Generally, a multitude of different methods is applied, each of them implemented for singular or limited process scopes. What was said for the processes also applies to methods – as methods are also core competencies of a design driven company, they need to be addressed across all lifecycle phases and spanning the entire company hierarchy. Methodical challenges in this context can cover incoherencies or incompatibilities in nomenclature, configuration or variant management approaches, or calculation methods (e.g. product cost for an assembly etc.).

2.3 Information Technology & Implications to PLM

The design environment is influenced and supported by many IT systems. IT solutions support the very early phases of a product development project by documenting and managing product requirements (requirements management). Going forward in the design process, IT tools are used for core design activities (Computer Aided Design - CAD) and for managing all product related data (Product Data Management - PDM) – 20 to 50% of engineering activities are spent on searching and determining the right information, depending on the level of innovation; this shows the importance of managing information for product development projects [6]. Finally, several IT systems are supporting all production processes and after sales activities (Enterprise Resource

Planning - ERP). This fragmented IT landscape needs to be coordinated and integrated based on an "Enterprise Architecture" to enable a cross departmental information flow [7].

Of the four dimensions of the engineering environment, IT is probably the one most contentious. The views on IT's value in supporting product development range from it being an important solution approach as such to reach both efficiency and innovation targets (e.g. [8]) to more critical views which reduce it to a poor supporting automation technology (e.g. [9]). Statistical evidence is provided for both views, showing that on the one hand good IT deployment correlates with business success, and on the other hand most IT investments result in failing implementations which do not improve or even worsen efficiency. As a consequence, the relationships of IT to the other dimensions of the engineering environment are controversial.

PLM is a strategic management concept for managing products along their lifecycle. Narrow views on PLM often focus just on the IT dimension as a supportive tool for established business processes and methods, then mainly in the form of PDM systems. In a broader understanding however, PLM features all four of the dimensions discussed above, all of them being interlinked and not to be addressed independently. Empirical studies suggest that this second understanding correlates with higher success rates of PLM implementations, and thereby higher business success [10]. In many companies, PLM is already seen as a strategic enabler for product innovation based on ideas and inputs from employees at various points in a product's lifecycle [11].

3 INNOVATIVE ENGINEERING ENVIRONMENTS

Engineering environments have changed over the past years quite heavily. While continuing this development of engineering and design work and methodologies, based on the outlined investigations and experiences the following areas should be considered.

3.1 Organization, Processes and Methods

Companies need to establish appropriate *organizational* structures to support a company-wide innovation management within a company-embracing innovation culture. Generic academic and pragmatic rules for innovation management can be found in well-known publications (e.g. [6, 12, 13]). From consulting experience one highly critical factor is the involvement of the top management for this cultural and organizational change.

Processes have to be honored as not something "just there", but as one key competence that enables industrial companies to perform [8]. Innovation needs a clear process basis, with possibilities also to initiate process change. Therefore, clear process responsibilities and governance have to be established and empowered on an organizational level. However, although innovation management processes are well researched, described and published, they are not consistently applied [3].

Companywide processes require common or at least harmonized *methods*. This is especially true in cross-x (with x representing domain, lifecycle and enterprise dimensions) engineering organizations. Bergsjö et al. [7] elaborates on cross-x methods integration on the examples of configuration management and change management, which represent key methods in any complex engineering environment. To achieve this harmonization a cross-functional and cross-departmental team needs to be established and empowered to govern and define these methods. This topic is often underestimated and needs top management involvement as well. This description shows that processes build the framework for the deployment of methods, thereby adding methods to the order within the engineering environment dimensions described above.

3.2 IT

Information technology's role is to support the defined processes and methods. Thus, there has to be a fit between IT concepts and solutions on the one side and processes and methods on the other side. Taking processes and methods for granted, well-fitting IT tools would have to be selected or customized. Taking IT solutions for granted, processes and methods would have to be adapted to the system-inherent (supposed-to-be) best practices. This fits to the management-popular approach of "no customizations", but may downplay the importance of distinguished, company-specific processes and methods. For this paper, we will follow the former, subordinated understanding of the IT dimension.

As a basis for such an architecture, a common enterprise-wide harmonized product information model is required to enable integration from a granular level, upwards. Only based on a sound informational foundation across vertical and horizontal organizational borders, an innovation-centric engineering environment can be erected. Based on the understanding of IT promoted in this paper, it is clear that this information model is not to be misunderstood as an IT-focused data model; it is to be established as an integrated approach with IT being just the enabling realization dimension. In the following chapter, a model will be introduced and referred to as the Enterprise Architecture Product Information Model (EAPIM), which is in core focus of ongoing and future research work.

Such a model needs to reflect all relevant information for different company hierarchy levels (vertical dimension) across the product lifecycle (horizontal dimension), see figure 2. The information model needs to be able to describe the business requirements of all relevant departments and groups within a company in a system neutral way to be able to reflect information from all dimensions: organization, processes, methods and IT data.

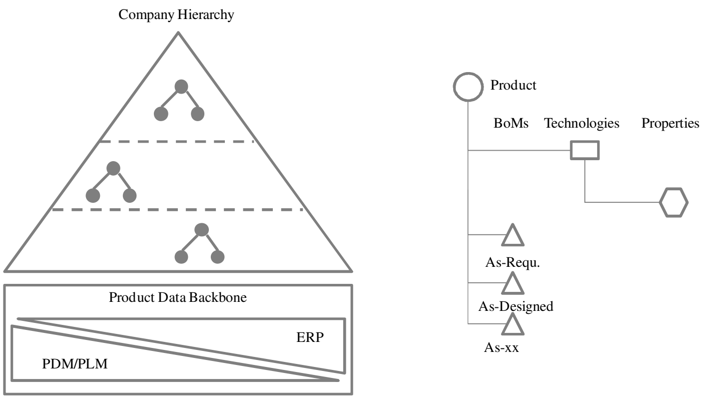

Figure 2 Concept of an Enterprise Architecture Product Information Model [3]

As a basis for further research activities the approach for documenting the new information model had to be defined. Based on experiences in process and workflow documentation a semi-formal approach will be used. Beside typical process documentation elements – process steps, roles, departments, triggers, inputs and outputs – the information model will include design information as well as process and production information [14]. One main objective of the new approach will be to target core product information and context information. Currently existing approaches and frameworks need further investigation regarding their usage in terms of a horizontal and vertical integration across the entire product lifecycle. An example and potential starting point for ongoing research activities is the “Engineering Object” concept as described in [15].

The following chapter will look in more detail at the concept behind and setup of the Enterprise Architecture Product Information Model.

4 Enterprise Architecture Product Information Model

The Enterprise Architecture Product Information Model is an approach to reflect product information in such a way that the entire enterprise can use this model. In order to position this approach a common understanding of the framework is needed where this model will operate. First, the element “*Enterprise*” needs to be defined. An enterprise can consist of a single company or a network of companies and/or including suppliers. In a first step and to simplify the model in the beginning in the following paragraphs we will limit this dimension to a single company – when talking about the “Enterprise”.

Within an enterprise there is a hierarchy to reflect responsibilities and power in an organizational manner. Within the hierarchy various roles are defined to perform different types of tasks to deliver their input for the value chain of the enterprise. Each role within the hierarchy relies on information to be able to perform its task. The required information dealing with product or product related information needs to be included and respected in the EAPIM (vertical integration). As an assumption for the approach discussed here – based on many years and projects in industry – the level of detail regarding the product data will differ depending on the level in the enterprise hierarchy.

As a second dimension in the enterprise hierarchy the horizontal integration needs to be introduced. Horizontal integration describes the information flow along the entire value chain within an enterprise. The EAPIM needs to be able to capture all different types of information required by the different phases of the product lifecycle along the chain.

The “*Architecture*” within the EAPIM approach describes the information management level including tools and methods. As stated before, in the context of this paper information technology is seen as a supporting technology for business processes. By this the architecture of tools and methods needs to be determined across the entire enterprise.

The next element to be defined to be able to discuss the research activities on the EAPIM is the “*Product*”. Experiences with different kinds of industries and various companies the definition of a product – even in long existing companies – sometimes is not an easy task. With regard to this paper and the presented approach we would like to discuss the definition of a product in context of this model. A product is a stock keeping unit (SKU) that is sold by a company to a consumer. By this definition a product can include one or many products. For example a car is a product, but if the automotive company is selling the engine as a spare part separately the engine as part of the product is also a product itself. But the product in this model is not only represented by parts/items as it is done in classical Bill of Material (BoM) approaches – moreover, a product is represented by technologies used to fulfill customer requirements in a certain market situation.

In our ongoing research activities the dimension of "*Technology*" was identified as mandatory to be part of the overall model to be able to cover the requirements across the entire company. A technology is seen in this context as a technical approach to fulfill requirements. For example the requirement "mobility" in the context of a car can be satisfied by the technology Diesel or Gas. Both technologies are realized in the product "engine" as building block of a product "car".

As the last dimension - the element "*Information*" will be described. As information in the context of the EAPIM all relevant product of product related information is covered. This includes also information around product requirements or product manufacturing or product maintenance. Experience within the topic PLM and Information management in research and industry highlighted the fact that structuring and limiting of information is key for a successful usage of information within a model. To support this, information needs to be captured and structured in so called "*Properties*". From an IT perspective these can be seen as attributes within a data model. But to stress this again, at this point in time within our research activities this paper is not discussing an IT solution or the IT realization, but showing an approach of modeling product information across the enterprise.

The assumption in the EAPIM is that properties need to be scalable depending on the level the property information is used within the enterprise hierarchy. Organizational roles performing their tasks in the enterprise hierarchy might need to have more detailed information than the roles operating on higher levels in the hierarchy. At the same time properties relevant for roles in higher levels in the hierarchy consist of one or many properties – originated in the lower levels of the hierarchy. It needs to be possible to represent dependencies and different kind of dependencies between properties.

In this paper the elemental building blocks of the EAPIM are introduced and discussed. The objective of the introduced approach is to satisfy the research question: "Looking at the current PLM solutions and the way these solutions are interacting with the organization and processes today – What are the requirements (boundaries) for a product information management approach to support the increasing amount and various types of information across the entire enterprise and along the product lifecycle?"

5 DISCUSSION

In chapter 4, considerations regarding the innovation-oriented design of the dimensions of the engineering environment have been discussed. They result from empirical observations from industrial and consultancy projects. In chapter 5, the Enterprise Architecture Product Information Model was introduced as one operationalization building block for a respective PLM setup. In the following, this will be set in context to the general dimensions of the engineering environment as described in chapter 2.

5.1 Organization, Process, Methods and IT interplay

Regarding product innovation the dimensions organization, processes and methods are well elaborated and addressed in research literature as well as partially also in innovation-driven companies. At the same time the dimension of information technology is not covered consistently at a comparable level – neither in literature nor in industrial practice.

Experiences within different global companies show that not only the four dimensions themselves are relevant but also the order and priority in which they are addressed within a company is critical. Several examples exist where companies intended to upgrade or replace their existing IT landscape in the area of product development. Because of the way however the projects were set up and positioned within the company they became pure IT-driven projects. Thus the other three dimensions were not in focus of the activities so the range of possible improvements was quite limited, standing against significant costs for IT implementation and rollout.

As a contrast, other PLM projects were also set up to replace the current IT solution, but to concurrently (or even beforehand) also revise and improve the existing product development processes and methods according to leading industry practice. Although giving a positive example regarding process-orientation of IT projects, these projects underestimated the impact and opportunities of the missing organizational dimension.

These two simplified examples show the relevance of all four dimensions for an engineering environment. Based on research and industry experiences in the area of product innovation and development they are to be seen as critical and crucial for process improvement and IT implementation projects. As currently a high percentage (84% acc. to [16]) of PLM programs are not successful new and holistic approaches are needed.

5.2 PLM as a lever

As described earlier, PLM is a strategic concept for product development featuring the same main building blocks: organization, processes, methods and IT. Therefore, this paper proposes to use PLM as a lever in the product innovation phase and as an underlying basis for the engineering environment. Preconditions are a defined interplay of all four dimensions, the right priority of these building blocks as described above and a broad understanding of PLM, accordingly. In combination with a comprehensive information representation (e.g. supported by EAPIM) PLM may enable companies to achieve even higher objectives in the area of product innovation. Figure 3 depicts the principles that are required to establish an engineering environment that enables and supports innovation. The current situation in many companies can be described as “flexible” or “undefined” in the early phase of the product lifecycle. This applies to all four dimensions – even literature and leading practice currently provide a variety of guidelines for the supporting innovation management in the areas of organization, methods and processes. To a certain level this flexibility or freedom is required to enable innovation.

Taking the assumption, that all the current existing knowledge regarding these three dimensions is widely established, the missing building block is the supporting IT in the early (i.e. innovation) phases. The intention of IT in that respect would be to support the business processes and provide the right information at the right time with the right level of quality. With this in mind, the concept of PLM can be one lever for innovation. Existing software products for innovation management or idea management are dealing with innovations and ideas as separate items described by a prose text. Moreover, the maturity of the innovations or ideas is tracked via the software by displaying the phase of the innovation process that the item is in. These standalone software solutions do however not provide the capability to interact and keep track with various sources of product information that are involved over the entire product lifecycle.

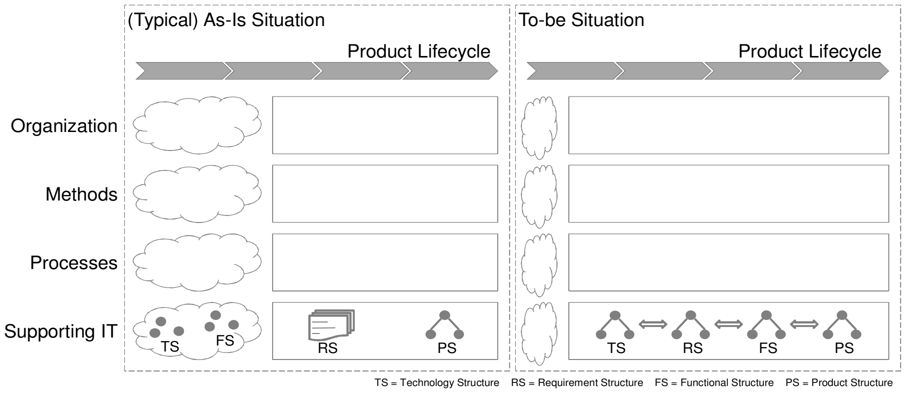

Figure 3 As-Is and to-be Situation of an Engineering Environment

In summary, an integrated concept of PLM across all four dimensions is a promising approach to developing engineering environments that enable product innovation. The underlying understanding of PLM is however crucial. The representation of information in the very early phase of the product lifecycle was identified as a major area for further research. Information representation is required not in terms of a data model for programming the final software solution but in terms of the information model (e.g. EAPIM) required to reflect and communicate the business process requirements.

6 CONCLUSIONS AND OUTLOOK

In this paper, the relation of the engineering environment, which is comprised of organizational, process-related, methodical and information technological elements, and the ability to innovate was discussed. It was pointed out that all four dimensions are interrelated with innovation, and that especially the interplay of all four dimensions is crucial for successful, innovative engineering. Dimension-wise, requirements regarding the organizational involvement of management levels, the integration and harmonization of business processes and methods and the underlying IT capabilities were elaborated on.

Product lifecycle management (PLM) has been discussed as a strategic business approach potentially providing a basis for an engineering environment, as it, in a comprehensive understanding, also comprises the same four dimensions as the engineering environment.

Revisiting the research questions from chapter 1, first answers can be given. Compared to the other dimensions, innovation-oriented IT concepts are not that well established. Especially an IT-based foundation in the form of an all-comprising information model is still lacking. The interplay between the dimensions of the engineering environment is crucial and should follow a logic of processes building on an organizational foundation, methods supporting these processes, and IT enabling both methods and processes. In this context, the EAPIM was introduced as a holistic approach for information modeling and main building blocks of this approach were described. The current state of this model does not yet give a full answer to the third research question, but it defines boundaries for upcoming activities and operationalizations.

The investigation of the defined building blocks has identified several areas follow-up research should focus on. As a next step, the deeper investigation and more detailed definition of the dimension “Technology” and the interdependencies to the common approach of the “Bill of Material” needs to be investigated. At the same time the interplay of the different structures or representations (requirement structure, functional structure, technology and product structure (various types) needs to be discussed to create a basis for the deeper definition of the EAPIM approach.

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Property test planning on the basis of a combined process and product modeling

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Abstract:

Nowadays automotive manufacturers have to face different global trends. Next to the increasing awareness of environment friendly mobility, resources will become smaller. More and more people will live and work in cities, the infrastructure of the transport sector will change, and the European society will mature. Last but not least emerging markets with a progressive innovation policy will change the future automotive sector. The challenge is to manufacture automotives with distinct properties and functions, which attend exactly to these high variably requirements. Therefore a property profile is necessary to be used as a guideline and synchronisation point for product development. This means that development targets as well as the current status of the project has to be communicated to each developing department. Thus this property profile has to be steadily evaluated along the product development process (PDP) in order to safeguard its fulfilment. Therefore a methodology should be presented in this paper how validation methods can be related to product properties or functions and how they can be arranged within the PDP according to their necessary input data. This should be done by the integration of a process and product model describing the property based product development as well as the used methods and tools within a semantic web. This creates a directed graph of the information flow within the property based development process.

Keywords: Product development process; property validation, process model, product model, semantic network

1 Motivation and objectives

Today a multitude of vehicle properties and functions have to be realized by automotive manufacturers to differentiate from the competitors. The challenge is hereby to realize all these requirements with a high quality standard within short development periods and with low costs. This can only be guarantied, if a quality deficit of the product’s properties and functions (for example a defective accelerator pedal) is detected early in the product development process (PDP). To realize this, the actual status of achievement of the product’s properties and functions has to be continuously monitored during the PDP (figure 1). This enables the continuous step by step drawback of the results of the product validation as well as the synchronisation and coordination of the module and component functions, geometries, and properties [9].

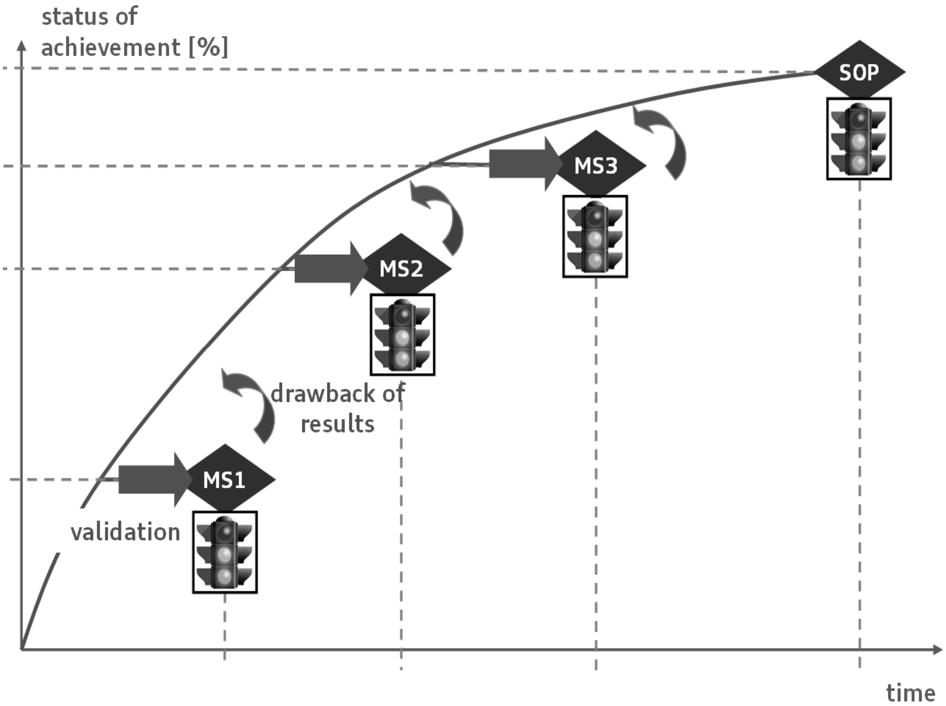

Figure 1: Monitoring the product development process via the properties' status of achievement

But a multitude of different and heterogeneous types of product representations is created and used during the product development process (from early sketches over specification lists, CAD files to hardware prototypes). Due to this fact a mass of different tools and methods is needed to analyze and to validate the product properties and functions on the basis of these product representations. Moreover the quality of the validation depends strongly on the ability of the used tools or methods, the available product representations as well from the property, which should be validated. In addition to this problem the creation of an analysis and validation model depends on the results of other analysis, which can lead to complex information chains (for example the creation of a MBS-model of a car needs the analysis of the damping ratio etc.).

Therefore it is difficult for the responsible project manager to estimate and to decide which tools and methods can be used at distinct periods of the development process to validate the product properties.

Thus the question arises how the responsible product manager can be supported by planning and the executing the product validation process.

To solve this problem a methodology is described in this paper, which should enable a transparently and consistently modeling of the product validation process. This is the basis for a further description of the information flow, which is necessary for the validation of product properties and functions. The information flow is described by a process model representing the different steps, by a product model representing the different data and documents occurring during the process and the used tools and methods, which are necessary to perform the different process steps. The conjunction of these three aspects is done within an ontology, which is a specific type of a semantic web.

The result of this analysis should be a property validation plan, which plots the tools and methods used to validate the product properties in a chronological order against the timeline of the product development process.

2 State of the art

The following chapter should discuss some fundamental theoretical approaches, which are relevant for this paper.

2.1 Process modeling

To represent the information flow of the development process it is necessary to have a look at the fundamental tasks of a product developer during the design process. According to WEBER'S CPM/PDD approach the product developer defines a solution concept during synthesis, which has to meet the requirements. This is done by influencing or determining the so called characteristics like structure, shape or material [12]. During analysis the properties, which describe the behaviour like safety or reliability of the created solution concept are identified. If the actual properties don't match the target properties either the solution concept has to be optimized or the requirements have to be modified. The benefit of WEBER'S approach for this work is that it focuses on the two core types of product information – the characteristics and the properties – and embeds them into a control loop like the TOTE-scheme, which ends, if the actual properties of a product match the target properties (requirements). Due to the fact that this procedure describes a problem solution cycle and is done many times during product development it is called a micro cycle.

A mechatronical approach is the VDI 2206 - *Design methodology for mechatronic systems*. It brings different domain specific guidelines together and deals with the development of a modern mechatronic product in its entirety. It describes the development process as the detailing of requirements (*system design*), the design process within the single domains (*domain specific design*) and the aggregation of analysis and their results (*system integration*) [11]. These three phases are embedded into a modelling and model analysis phase. Next to this reason and the fact that this guideline supports the macro cycle of mechatronic products it is very important for this paper, because it models the information flow considering the product structure and hierarchy (from the whole product to the domain specific component).

2.2 Product modeling

To create a generic information flow it is also necessary to classify and model the product information during the development process. Product information occur within documents or data, which should be designated as product representations within this paper (e.g. specification lists, or test reports). According to ANDERL the product model is the result of the PDP and describes the product in a formal way and documents all relevant properties and characteristics during the PDP [2]. This formalization enables therefore the exchange as well as the interoperability of product information and is the fundamental basis for every product data management. GRABOWSKI et al. specifies the term product model and defines the so called integrated product model, which consists of different partial models representing different views (lifecycle stages, disciplines etc.) [1]. The most important approach to describe these partial models is the DIN ISO 10303, which has different application protocols (APs) for different views or domains (for example the AP 214 for the automotive industry. Moreover some application protocols describing properties and requirements – the DIN ISO 10303 AP 233 *Systems Engineering Data Representation* and the DIN ISO AP 235 *Engineering Properties for Product Design and Verification* - are state of the art. The expansion of these application protocols is still a current research topic [8]. These application protocols are the basis for the clustering of the partial models described in chapter 3.2.

2.3 Ontologies

Ontologies are able to model different types of information and consist out of four basic parts. Concepts are used to classify information, whereas instances are used to represent information. The concepts and instances can be connected by different types of relations (e.g. "is a"). Additionally domains and ranges can be used to create constraints for the relations. Ontologies as a subtype of semantic webs become more and more important for the modelling of product information, because they are able to handle and to interchange knowledge [10]. Next to the attempt of describing and handling information of different domains, ontologies are used to retrace information and to analyse information along the product lifecycle [3,7]. In contrast to classical data or product models ontologies are able to model classes, relations, attributes, as well as concrete product representations like CAE-models as instances. Therefore it is possible to group product representations together in a product model and to link them to a process model, which can also be modelled in ontology. Due to these benefits an ontology is used in this paper to represent the information flow, because it is possible to create a meta model as well as to model the product representations in one software environment.

3 Methodology for the description of the information flow

In the following chapter a methodology should be described how a linkage between the product and the process model can describe the information flow, which is necessary to validate product information.

3.1 Process model

To describe the product development process it is necessary to combine the micro and the macro process. Thus it is necessary to consider the correlation between characteristics and properties (micro process) as well as the correlation of properties along the product structure or hierarchy (macro process). Due to the fact that the control loop describing the micro cycle was only fundamentally described it has to be enlarged on the steps requirements synthesis, analysis model creation and the evaluation. During the requirements analysis the requirements are described with objective or subjective measurable quantifiable target properties [6]. During synthesis the product characteristics are defined by the designer (see chapter 2) and are filtered, pre-processed and assembled to an analysis model during the model creation step. In the following the product properties are analysed (for the calculation of the *system pressure* of an air supply aggregate a simple model of the *piston force* and the *piston area* is needed. This *piston area* can for instance be pre processed out of the *geometry* of a CAD-model). And finally these actual properties are compared with the target properties. This evaluation decides if the next step of the macro process can be performed or if an further optimization loop or even a modification of the requirements have to be performed.

Considering HERFELD this has to be done along the product hierarchy, whereas the solution concept of a top layer defines the requirements for the next deeper layer (for example the property *driving comfort* of a vehicle (product) requires a special *suspension* (assembly) as solution concept. This *suspension* requires a distinct *damping ratio*, which should be realized with an *air damper* (subassembly). This *air damper* requires again a distinct *system pressure* of the *air supply aggregate* (component)) [4] (figure 2).

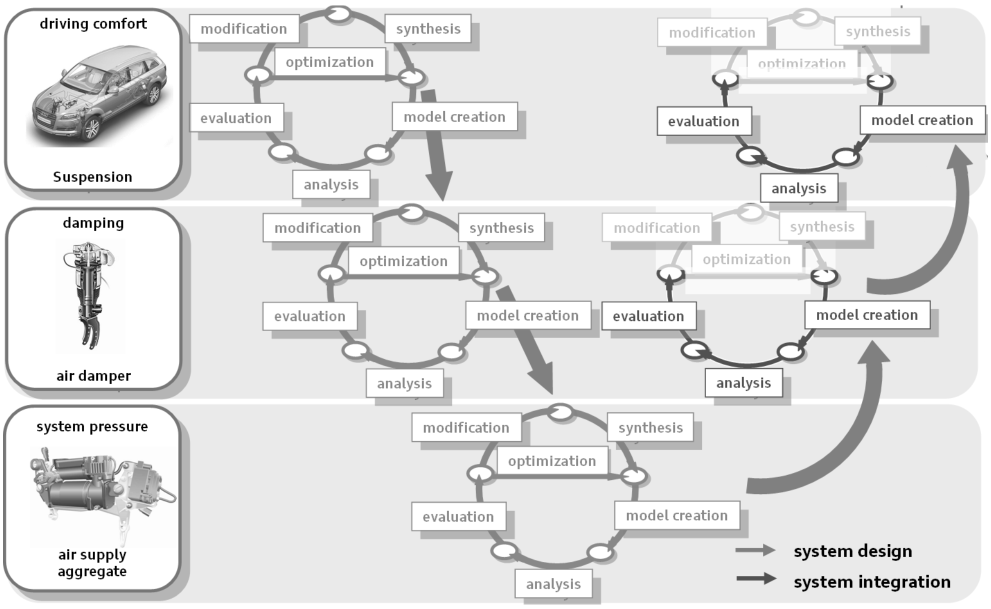

Figure 2: Process model of the product property validation

Therefore the micro cycle has to be processed on every layer of the product hierarchy until the solution concepts fulfils the requirements, which are dedicated from the solution concept one layer higher in the product hierarchy (figure 2).

During detailed design each discipline has to create solution concepts for their components. And finally those solution concepts are tested and assembled to sub assemblies, assemblies and to the product in order to evaluate the properties und functions during system integration. But unlike the system design phase the system integration phase has no synthesis, modification or optimization steps, because if a property isn't fulfilled a drawback to the system design phase is necessary. Consequently it can be postulated that the macro process of the PDP is a distinct sequence of the micro cycles of different layers of the product hierarchy.

3.2 Product model

As mentioned before a product model is a formal specification of the product information and should support a standardized description of product information as well as the management of product representations. To capture all product information it is necessary to investigate the product representations about their containing information. Consecutively these pieces of information have to be classified in objects and related to each other in order to create a product model (for example as an entity relationship diagram).

In order to handle major product models it is necessary to create so-called partial models. Figure 3 shows the main objects of the product model as well as their arrangement. In this product model product properties are arranged within a property structure. Assessment criteria are used to describe those properties on a measurable level (for example the property driving comfort can be described with a maximum yaw angle, which can be measured during an ISO lane change manoeuvre (also called moose accident test)). Three kinds of assessment criteria exist for the description of the target properties, of the actual properties and for the current status of the properties (comparison between target and actual properties). The target properties are requirements for the solution concept. This solution concept consists of a chosen principle functionality of his product or component and characteristics, which has to be defined by the designer. The designer has to define the fundamental parameters (for example the geometry or the material) the structural architecture as well as the configuration of his product. The analysis model is an assembly of distinct characteristics or distinct components out of the solution concept and has to be analysed within a test scenario (also called load cases). These test scenarios can be grouped, too (for example NCAP crash scenarios). The results of an analysis are the actual assessment criteria, which have to be compared against the target assessment criteria in order to evaluate the status of achievement of the solution concept (figure 3).

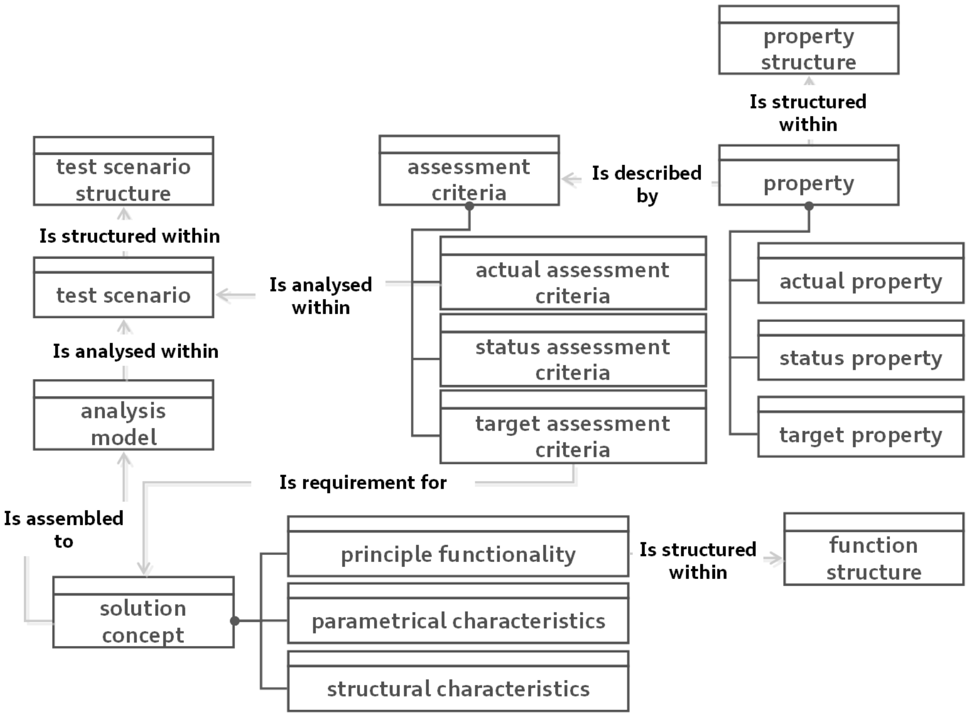

Figure 3: Product model of the product property validation

Though this is just a very high level view on the classification and relation of product information, this is basis to group theses objects into partial models. The properties, their structure and the describing target assessment criteria as well as the description of the test scenarios and their grouping display the partial model “requirements”. The partial model “solution concept” consists of the meta description of the component as well as the characteristics and the description of the functionality. The partial model "analysis model" consists of the different models, which where build up for testing the properties. The partial model "analysis result" displays the actual assessment criteria and therefore the actual properties. And finally the partial model "evaluation" consists of the status of the assessment criteria and therefore of the status of the properties. The last two partial models can be structured like the requirements within a property structure.

3.3 Modeling the information flow by the integration of the process and product model

The information flow can only be modelled if the product model can be linked to the process model. Moreover it is necessary to access different types of skills to each process step in order to measure and analyse the ability of the process in order to plan and execute a quality management.

The linkage of product and process information has to be dynamic to represent the development process. Consequently the product and the process information can't be directly linked. Instead the product and the process information have to be abstracted and modelled within meta-models. On this level a generic linkage between the process and the product steps is possible. Thus each process step results in a distinct partial model and each partial model is used for a distinct process step.

This enables a generic mapping between the process model of the micro cycles and the partial models, because each of the six main process steps transform information of a distinct partial model to an other distinct partial model (for example a crash analysis uses a FE-model (analysis model) as input and calculates the maximum deformation (analysis result)). Now it is possible to generically map each product information of an object within a partial model to a distinct process step (for example the maximum speed as a target assessment criteria is always used as input for a synthesis step as well as an input for an evaluation step).

Thus the requirements elicitation step results in the partial model "requirements", the synthesis step results in the "solution concept" the model creation step results in the analysis model, the analysis step determines the "analysis results" and the evaluation step determines in the partial model "evaluation". Considering the product hierarchy the "solution concept" as described in chapter 3.1 can be defined as "requirements" for one level below within the product hierarchy during system design or it can be assembled to a solution concept one level higher within the product hierarchy during system integration.

4 Ontology based Integration of the process and product model

The conjunction of the described process and product model was built up in the ontology editor Stanford Protégé [5]. As mentioned in chapter 2 ontologies are a special type of semantic webs and have pivotal benefits of connecting and relating information. First of all three stand alone T-boxes have to be modelled in order to represent the product model, the process model and the tool & methods model (figure 4). In the following these three "sub"-ontologies can be connected within a top level ontologies, including the relations between the different concepts, as well as the ratings of the quality of different process steps in dependence of the used methods & tools as well the used product models.

The process model ontology is used to describe the micro cycle of the PDP (chapter 3.1). The product model ontology is used to describe the product model with its five partial models (requirements, solution concept, analysis model, analysis result, evaluation) (chapter 3.2). The tools & methods ontology has to be created to model the tools and methods which are used during the development process. By defining domains and ranges for the relations it is possible to assess which concepts of the product model can be used as input for distinct process steps, in order to model the information flow (chapter 3.3)

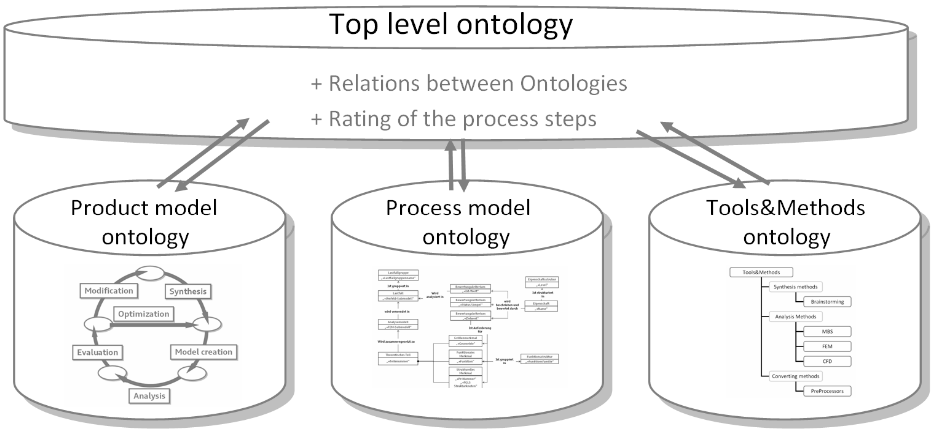

Figure 4: Meta model of the ontology

The next step the ontology is fed with test data to create a data basis. Therefore product representations are modelled as instances within the ontology and were linked. To analyze the information flow, which is necessary to evaluate product properties, some queries have to be verbalized. These queries should enable to sum up the expenditure of time of all process steps of one information chain, to display the necessary tools and methods, to calculate the quality of the whole information chain and to identify the components out of the solution concept which are necessary to evaluate the product property (figure 5). This is the basis for the creation of a validation plan, which displays the chronological order of the property validations in dependence of the tools and methods and their necessarily and available input data (solution concepts).

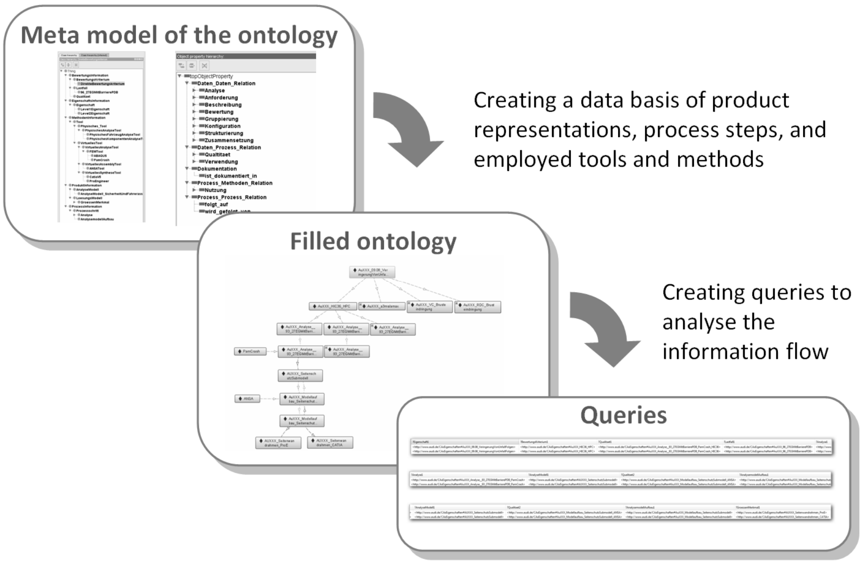

Figure 5: Ontology based analysis of the product validation process

5 Summary, discussion and outlook

A methodology for the modeling and analyzing of the information flow of the product property validation process was presented in this paper. The abstraction of the process and the product information enables the creation of a process and a product model and their conjunction. The additional consideration of the employed tools and methods enabled the allocation of an ability or quality to each process step, which is the basis for a analysis and quality management of the product validation process

This shows the possibility to model the information on the basis of a process and product model. Moreover the methodology can be realized within an on ontology which can be used to analyze the product validation process in the design integration phase. Consequently a quality management – like it is performed in the product area or the supply management could be established in the property validation process. This would strongly support the responsible project manager in planning and coordinating his or her validation and test processes.

Nevertheless some questions are still not fully solved. On the one hand the deduction of requirements during the system design phase is highly iterative. Therefore it is possible to model a single iteration loop but it is almost impossible to model the number of iteration loops. Consequently the chronological analysis is very difficult. Another aspect is the interaction between physical and virtual validation processes. In many cases virtual validation results have to be verified by physical tests. This leads to additionally iteration loops which can hardly be forecasted.

Thus the methodology has to be enlarged in order to model these iteration loops and distinction of cases. A second aspect is the computing and visualization of the query results in order to create a tool, which can easily be used by the project manager.

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Reducing the variant diversity in spare parts management

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Abstract: Due to the high margins that could be achieved independent from economic trends spare parts management gains more importance. Furthermore only a high service-level during the product lifecycle can ensure customer satisfaction and loyalty. But the customer demand created a steady trend towards a greater product variety, which has a high impact on spare parts management. Spare parts have to be available for several decades in some branches. Therefore the number of active spare parts has increased in a high degree. Especially innovative parts, like electronics, create further problems in spare parts management for long-living primary products concerning storage or availability. To cope with these challenges an efficient variant management has to be implemented. The general principles of variation management must be adapted to the context of spare parts management.

Keyword: Spare parts management; Variant management; After sales service

1 Introduction

Social, technological and ecological changes as well as complex external requirements are met by many companies with activities that lead to an increase in complexity. [1], [2] This is particularly true for the product complexity, which has increased tremendously in the past due to the differentiation of the demand structure and more niche products. [3] The change from a seller's to a buyer's market, shorter product life cycles, an increased pressure from global competition and a focus on customer needs enforce this trend. The decrease in quantity for each variant combined with the increasing number of variants and customer demand for shorter delivery times and for increasing quality, demands further adjustments of producing companies. [1] For example between 1990 and 2002 the number of body types produced by the top eight vehicle manufactures in Europe rising from 88 to 179. [4]

A variant of a technical system is defined as a “different technical system with the same purpose, which differs in at least one relationship or one element. An element is different from another element in at least one property.“ [5] The reasons for the emergence of variant are diverse [5], [6], but can be clustered into three groups:

1. External Reasons,
2. Market and
3. Internal Reasons.

An external reason for example is the technological development, resulting in shorter product life cycles, new technologies and opportunities for global information of customers. Also, social and political change causes changes that force companies to offer an increased number of variants. One example is the demographic change in many western industrial countries, which has to be met with special products for older people.

Market reasons are for example the shift from a seller's to a buyer's market. To win new customers, more individualized solutions are necessary. The saturation of existing markets and the emergence of new markets can lead to higher product diversity. Many industries that operate on global markets are faced with demands for challenging functions, an increased complexity and thus a high diversity of their products. [5]

In addition to these external and market reasons for the emergence of variants are often also internal causes identified that lead to a high number of variants. For example, the cost situation leads to the production of niche products. Often the attention in a company is not centered towards costs and disadvantages of variety because of methodological and organizational deficits. [5]

The increased number of variants increases the effort in many business areas, such as the development, logistics, manufacturing, distribution and service. [6], [7] In logistics, for example, difficulties in the material requirements planning and the smaller lot sizes lead to an increase of the purchase prices. An inventory of all product variants would increase stocks of the company tremendously. The result is either a reduced delivery performance or higher inventory costs. Also the costs for the search, selection and care for the supplier increase with the number of components used. [8] Especially because in most branches the supply period is clearly longer than the serial production, variant management has a particular meaning for the spare parts management. In the automobile industry the serial production lasts between 5 and 7 years, meanwhile the supply period is up to 15 years. [9] That means, the spare parts for the different variants have to be available for quite a long time even though the demand for some variants may be very low and is hard to forecast. Variants that can be sold to a reasonable price just with a financial deficit for the enterprise cannot be sorted out. This special condition in the spare parts management has to be taken in account in the variant management.

The main research objective of this paper is therefore the transition of the general principles of the variant management for the spare parts management in consideration of the given parameters.

2 Variant management

2.1 Objective of the variant management

The main objective of variant management is to realize a profit-maximizing variant diversity. The customer requested external diversity must be produced at low cost and thus with a minimal internal diversity. Unnecessary variants or variants with a low demand should be avoided altogether [3]. By reducing the number of variants a simplification of processes may be achieved [5]. In addition to avoiding unnecessary variants, the necessary variants have to be structured and managed optimally. The two most important measures to achieve an efficient production despite a high number of variants are a late customer order decoupling point in the value chain, and to achieve variance through configuration of defined modules rather than to design each variant individually [6]. Therefore measures are necessary to re-use components and the systematic design of structures with variable modules and parts. The harmful internal diversity is a measurement of the number of different modules, parts, and production processes. This internal diversity results in a high complexity in production, logistics and further departments. The costs for manufacturing will rise consequently [10], [1]. The external diversity is perceived by the customers. It helps to fulfill the customer requirements and increases the customer benefit. Consequently it should be maximized as seen in figure 1.

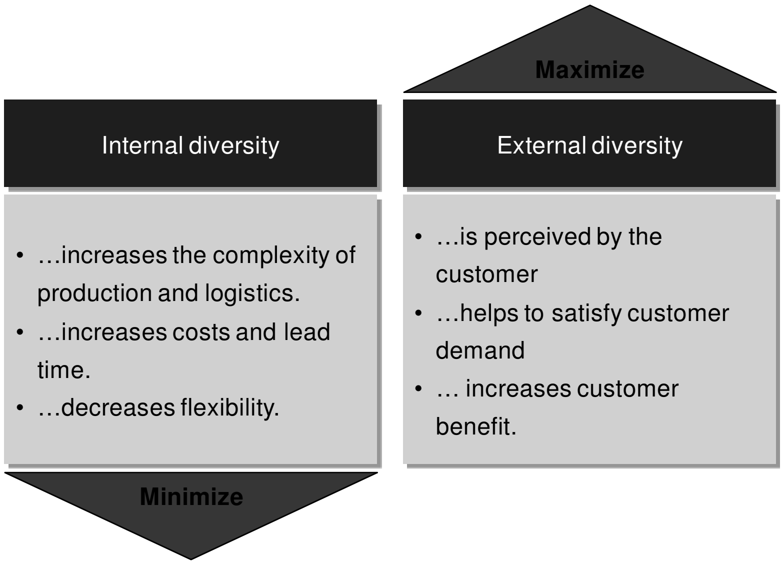

Figure 1 Internal and external diversity

2.2 Measures of the variant management

Based on the company's objectives the strategic variant management set the long-term planning of the optimal variant diversity. The operative variant management considers as basis the results of the strategic variant management and attempts to achieve the defined objectives with minimum costs. The experience accumulated with the operational management are involved in strategic planning again.

In principle four different types of variant management can be distinguished [10]:

1. Variance prevention: The greatest potential for rationalization is the early prevention of variants in the product development. Just variants with an estimated high customer demand should be developed and produced.

2. Variance reduction: From the start of production, the number of variants increases due to the demand of the customers. Due to changes in the preferences of the market the volume of some variants may decrease, so that an economic production is not possible anymore. It is necessary to sort out inefficient variants. Those variants, which make up only a small contribution to business success, but simultaneously have a high degree of differentiation to other products, are potential candidates to be stopped.

3. Variance outsourcing: The outsourcing of the production to specialized facilities or suppliers reduces the variety of production in-house [10]. The problems are not solved but transferred to a partner who can deal with the high variety in a more efficient way.

4. Variance control: Measures to design the production processes to deal with the high variety. The goal is not to reduce the number of variants, but to produce them more efficient. One possibility is to reduce the set-up times between the variants for example with SMED (single minute exchange of died). Main objective are a higher flexibility, a better utilization of the manufacturing equipment and lower lead times [11].

3 Spare parts management

The efficient provision of spare parts over the entire life cycle of a product is a quality feature that may differentiate the enterprise from the competition. It is leading to improved customer retention and thus strengthens the company in the market for long term [12], [13]. Secondly, there are also often legal obligations, such as laws or even bilateral agreements between companies which require the availability of spare parts for a defined period. A basic requirement of a successful spare parts management is therefore a long-term availability. Furthermore, the spare part management must also meet the requirements of each company in terms of economic profitability [14].

Wear parts such as brakes and exhaust of the automobile have an easy to forecast replacement time due to defined fading. In contrast failure parts as electronic control units are designed to cover the entire life cycle of the product without defect. However, it may be due to external influences, such as an accident, or because of internal influences, such as a production error, a failure is caused. A forecast of the demand is therefore difficult; furthermore also the numbers are very low relative to the wear parts. [15] [13] In particular, if failure parts include highly innovative components, as for example in electronic components, long-term production possibilities are often unclear. The production of semiconductor components, for example, is just about two years. [16] Despite these problems, these parts must be continuous available until the "End of Service". The high innovation rate in electronic components is based on the continuous development of technically more sophisticated, cheaper and more efficient components and products.

In the post series supply six supply strategies are common. Every strategy has different requirements and also significant impacts on the variant management. These six supply strategies are [13], [15], [17]:

1. Use of compatible parts: Products of the next generation are downward compatible and can be used as spare parts for the previous generation and thus be taken from the serial production. The costs for production are therefore significant lower than with most other strategies. However, due to the fact that technological restrictions on product development in this case are very high, in practice this strategy is seldom conducted.

2. Stocking of a final lot: Based on the estimation of the lifetime demand a final lot is produced either at the end of serial production or at a point in the supply period when the reproduction is not efficient anymore. A restart of the production is not intended;

therefore the manufacturing equipment may be disposed. Major problem is the demand prognosis, because both an overstocking and an underestimation will lead to high costs. Either surplus parts have to be scrapped or a costly redesign of the component has to be done.

3. Periodical internal reproduction: After the end of serial production spare parts will be manufactured periodically in small lot sizes according to the actual demand. Therefore the manufacturing and testing equipment has to be maintained and the electronic components have to be available.
4. Periodical external reproduction: Often the Original Equipment Supplier (OES) is specialized on the serial production with large lot sizes. The spare parts manufacturing does not fit into the normal production program, therefore it is outsourced either to a third party or a specialized division in the enterprise.
5. Repair / Remanufacturing: The repair of used components is often cheaper than the production of a complete unit. Furthermore the repair process can also be carried out, if electronic parts are not available any more. It is necessary to establish a reverse logistics network to gather enough parts. Furthermore during product development the requirements of the repair process have to be accounted for.
6. Reuse of used parts: Used components may be used without any remanufacturing. Especially when the amount of returns is high, as it is in the automobile industry after the directive on end-of-live vehicles in the European Union many used components are available which can be tested and used as spare parts without any remanufacturing.

In practice, the combination of several supply strategies to a supply scenario is often necessary due to changing parameters during the supply period. For example, the demand drops steadily and the price sensitivity of customers increases with the age of the primary product.

4 Modification of the variant management

To support an efficient and economical spare part management, it is necessary to establish a variant management. This must be adapted to the specific requirements of the post series. Until now there are no successful approaches in the literature mentioned. Because of the specific parameters in the spare parts management, such as the limited availability of components a direct transfer of innovative production concepts like mass customization is not possible. As a solution for the research question this paper shows how the variant management can be adapted to the specific parameters of the spare parts management. The developed concept will be validated in an practical example as described in chapter 5.

In the following, the four already described measures of variant management are examined in terms of their suitability for use in the spare parts management and adapted if necessary.

1 Variance prevention: A prevention of the appearance of variance can only be made in product development. At this point already, the requirements of the post series have to be considered in order to prevent possible problems.

One possible measure to reduce the internal variance is a product customization through software instead of different hardware variants. Especially in the automotive supply industry in the production of control units, it is common to install different software versions on one hardware variant to increase the external variance. [17]

2 Variance reduction: This is for the spare parts management just in rare cases an option. To meet the needs of customers in terms of long-term availability, an abandoning of individual product variants cannot be made just because of economic reasons. In addition, in the automotive industry often a contract between suppliers and Original Equipment Manufacturer (OEM) regulates that parts need to be offered for ten to fifteen years. The elimination of only economical unjustifiable variations is therefore not an option. Only the supply strategy "using compatible parts" offers the chance to eliminate part numbers by using other variants that are still in serial production.

3 Variance transfer: This approach is already common in the spare parts management to reduce the variance of the own production with the supply strategy external reproduction. Thus companies have established so-called spare parts factories, which are specialized in the economical production of small lot sizes and hold testing and manufacturing equipment and the necessary know-how for several decades. Furthermore, also independent small manufacturer, the so-called Electronic Manufacturing Services (EMS), gain more and more market share.

4 Variance control: This approach is in the spare parts management directly applicable and promises short-term success. In the next, a practical example is used to explain how the variance in the post series supply leads to problems and by what practical measures of variance control that could be defused.

Depending on the industry branch and the specific project the priorities are set differently. For example, the production of mechanical spare parts shows strongly different parameters as the production of electronic spare parts. Therefore an universal procedure is not feasible.

5 Practical example of variance control

In the following the adapted variant management will be discussed on a practical, representative example in which the approaches of the variant management were transferred to the spare parts production.

The starting point was the increased variance of the production program of an automobile supplier, which produced electronic control units. The number of manufactured product variants increased continuously. At the same time the average annual demand for each variant dropped. From 2004 to 2008 the demand per variant declined by 44% of its initial value, while the total amount of all manufactured products remained constant. Resulting are high time slices for the setting and starting up of manufacturing facilities. Main objective for the project was to develop measures to deal with the variant diversity in order to increase the productivity and foremost to shorten the lead time. [1].

A detailed analysis of the production program considered the annual demand quantity for each of the 1,500 active variants. The identified differences were tremendous as shown in figure 2. Some variants were asked in quantity one, however, other variants had a volume of about 100,000 units. The average was an annual demand of 3,500 units. To determine the variation of lot sizes, the standard deviation of customer orders was analyzed. 60% of the variants are available on a regular basis, i.e. the relative standard deviation is less than four ($\sigma < 4$). However, 30 % of the products were ordered unbalanced ($\sigma > 8$). Furthermore, there is a not negligible amount of product variants which were ordered very irregular (10%). The analysis revealed a strong correlation between the annual demand and the standard deviation. With a high annual demand a regular demand can be expected. In contrast, smaller annual demands go along with a larger fluctuation.

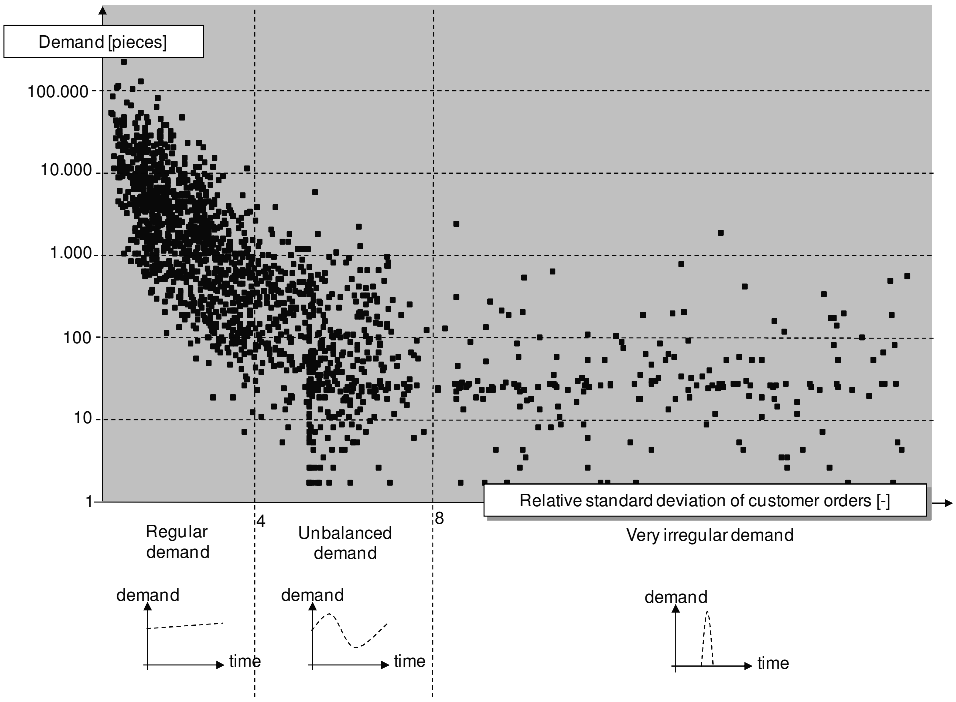

Figure 2 Annual demand and standard deviation [1]

The regarded manufacturing area was a PCB (printed circuit board) production line, quite typical for the electronics manufacturing. Already in the first step of the production process the product family is determined as shown in figure 3. The final product variant is defined in the current production structure after the mounting of the electronic elements and the assembly when the variant-specific software is installed. In the structure of production are thus two customer order decoupling points (CODP). Afterwards the component gets a sealing, which has to harden several days. After a final test, the components will get packaged and put in the storage. Thus, at first the printed circuit board determines the product family and then the product is defined with the installation of the software. Since the decision about the product family is imperatively at the beginning of the production process, the project focused on the second CODP, the installation of the variant-specific software.

One major problem in the actual arrangement of the second CODP is that the installation of the software is before the hardening of the sealing material. While the lead time for mounting and assembly together has an average of less than three hours, the hardening requires 48 to 72 hours under defined climatic conditions. Due to the lengthy hardening process and thus the long overall lead time, short-term customer demand or minor changes in the orders cannot be fulfilled flexibly. Short delivery times and high delivery reliability therefore may only be realized by high finished goods in stock.

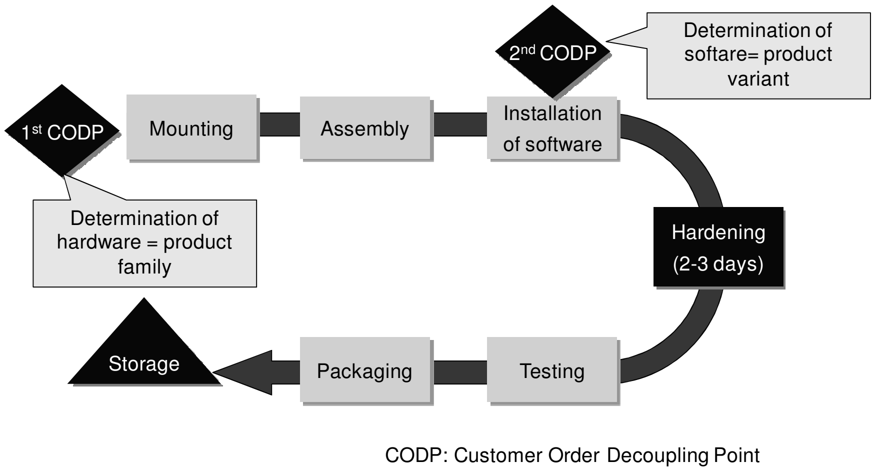

Figure 3 Actual manufacturing process

Various approaches have been developed to achieve a better variance control through changes in the production process. In the present paper, the after a simulation selected alternative is described [1].

Product variants which have constant demand will be produced furthermore in the assembly line with their variant-specific software without any changes and will be on storage. However product variants that are demanded by the customers in small quantities, on an unbalanced or very irregular basis are not kept in stock of finished goods any longer. Within a newly introduced supermarket each product family is represented with at least one variant, the so-called standard variant. In the case of a small order the customer order is fulfilled by changing the software of the standard variant to the desired variant. The distinction, at which order volume a manufacturing order is established or if a standard variant is changed, is done by a determined lot size. To replenish the supermarket, the required quantities are combined to produce based on the product family. Production is thus relieved of orders with low quantities.

The described alternative includes on the one hand the benefits of the economical production in large lot sizes in a fixed manufacturing line. On the other hand, higher efficiencies through reduced set-up times and increased flexibility are achieved. The reprogramming of manufactured products, although an additional expense, however, means a considerable discharge of the finished goods warehouse. The total inventory can be reduced significantly. One disadvantage is the increased control effort for the manufacturing processes and the newly installed supermarket. If all production orders with a volume of less than 100 units are served from the supermarket, the average lot size will increase by almost 40%.

The approach achieved in the example good results. In the practical example was shown that measures of variance control have a high impact on the complexity and thus and economical success of spare parts management. However the approach and the selection of methods always depend on the individual case. Variables such as lot size, version number or the stability of customer demands are crucial for the correct procedure.

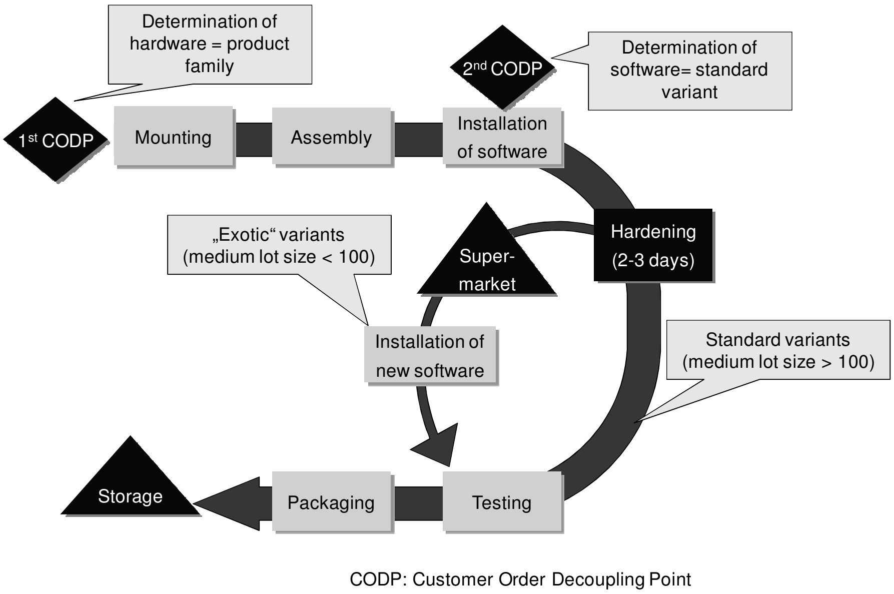

Figure 4 Optimized manufacturing process

Conclusion

The use of variant management in the post series supply is a useful approach to reduce the resulting expense caused by the high number of product variants. This paper shows that not all measures of the variant management can be employed reasonable due to the characteristics of the spare parts business. Variance can only be prevented in the product development. For the purposes of the spare parts management is the early consideration of the requirements of the post series a meaningful step to reduce the life cycle costs, which are also determined by the supply of spare parts. However, this is a long-term approach that can be used for future products, but does not affect the acute problem situation. The reduction of variance through the provision of unprofitable parts cannot be done because of the reputational damage and a subsequent high level of customer dissatisfaction. Outsourcing of the variance to specialized departments or to third parties is an approach that relieves the company in the short term, but only shifts the problems. To diminish acute problems variance control can be applied. In a practical example, it was shown how to change the manufacturing and logistics concept to reduce the negative impact of variety on economy and efficiency of production.

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Authoring and verifying vehicle configuration rules

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Abstract: Vehicles require large set of configuration rules defining which vehicles that are allowed to be built. Incorrect rules may have expensive consequences, e.g. faulty configurations with missing parts in production. This paper aims to investigate industrially applied methods for authoring and verifying configuration rules, specifically to understand the difficulties that potentially may lead to faulty configurations. The research method was mainly by interviewing design engineers and product structure specialists at three large automotive companies operating in-house developed Product Data Management systems for the product structure. Both roles want configuration rules that are easy to read based on their specific needs. However, their needs differ due to different daily working activities. Our main contribution is to formally define the authoring methods that we have found during the interviews, and to analyze their strengths and weaknesses during the verification activity.

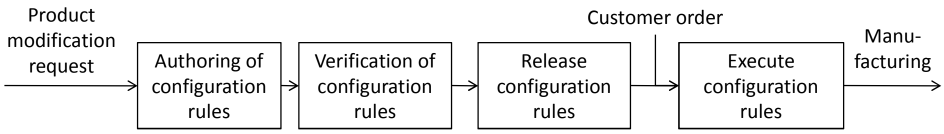
Keyword: configuration rules, authoring methods, verification methods

1 Background

This paper aims to investigate industrially applied methods for authoring and verification of vehicle configuration rules, specifically to understand the difficulties that potentially may lead to faulty vehicle configurations and inefficiencies in the configuration rule development process.

Configuration rule modifications are usually requested by new development projects, facelifts or modified market offering, but may also be requested due to discovered quality issues. The configuration rules are authored using certain methods, and are then verified before the release, see Fig. 1. Both design engineers and product structure specialists are involved in authoring and verification of configuration rules. These roles have different daily activities, which generates different preferences in authoring methods. There is also a risk of misunderstandings between the two roles when developing the configuration rules. When the configuration rules are released they may be used within the order system, where they are executed when verifying that customer orders are allowed to be manufactured. The paper's scope covers the authoring and verification methods of the configuration rules, which is in contrast to the more commonly researched topic the execution of the configuration rules as in [1, 2, 3]. Efficient authoring and verification of configuration rules is becoming increasingly important, due to increasing industrial needs and increased capability of supporting these needs by formal verification techniques. The industrial needs are at most automotive companies increasing due to the vehicle complexity and harsh competition.

Figure 1 Schematic picture from the change initiation of the product structure to manufacturing, with this paper's scope marked in dotted line.



Some papers claim to know how to identify the flawed configuration rules, for example [3, 4]. Others claim to have automated the support for debugging of configuration rules, for example [5]. These authors do however not address the complete issue, since what the authors are discussing is the algorithm for how to calculate which vehicle configurations that are allowed to be built according the configuration rules. Looking at the automotive industry, there is nothing flawed about a vehicle configuration that is not allowed to be manufactured, if it should not be according the strategy from the product planning department or the design engineers' feasibility studies. Following this line of argumentation, paper [4] states that it is yet to be proven for how to verify that the product structure is correct. In the future maybe, the configuration rules will contain enough information to fully automate the verification of configurations. This paper studies the design engineers and product structure specialists reasoning when authoring and verifying configuration rules. The results shows that both authoring and verification is done by visually examining the configuration rules, which is an activity not yet described in the literature at least to the authors' awareness.

The remainder of the paper is organized as follows. The definitions used are presented in Section 2. Research questions, data collection methods and interview strategy are presented in Section 3. Section 4 presents the results from the study, Section 5 the validation of the results, Section 6 the conclusions and Section 7 the future work.

2 Definitions

Vehicle configuration requires two product structures, one feature (variant)-oriented that is related to the options that a customer selects in sales configuration, and one item-oriented structure that is related to design and manufacturing. Therefore, vehicle configuration requires several different kinds of configuration rules. The definitions used in this paper are presented in Fig. 2, but have also previously been described in [6]. The top node of the information model is the product family, defining e.g. all vehicle models sharing the same platform. Within the product family there may be several product models, e.g. the basic and luxury version of a medium-sized vehicle. The vehicles within a product model is specified using features, which were mentioned as early as in 1982 by Mather [7], who claimed that the features are necessary when the product variety is too large to define a product number for each developed product. Selecting one feature variant from each feature family creates the vehicle specification. The feature variants are variable product features, e.g. the "exterior colour white" or "exterior colour red".

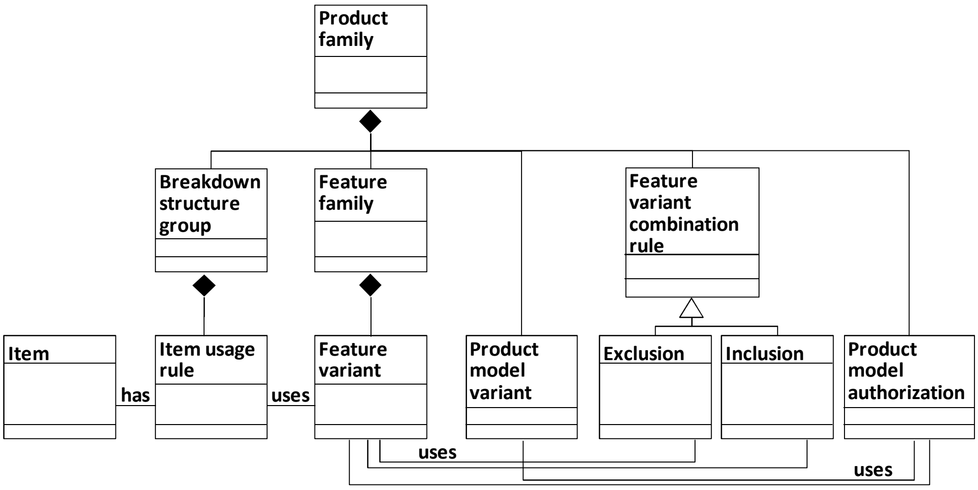


Figure 2 Information model for the product structure commonly used in the automotive industry, adapted from [6].

The allowed combination of feature variants are controlled by three types of configuration rules called exclusions, inclusions and product model authorizations. There is a fourth rule type called "item usage rule", which declares for which feature variant combinations the items, e.g. components, documents or interfaces, are used. The configuration rules are thereby:

- Product model authorization rules define for which product model variants (e.g. Volvo V70, BMW 3 Sedan etc) a specific feature variant (e.g. sunroof) is allowed.
- Feature variant combination rules that define prescribed ("inclusions") or forbidden ("exclusions") combination of feature variants.
- Item usage rules, which define for what feature variant combinations a certain item, should be used.

The first two bullets are called variant combination rules and exist at the studied automotive companies but the company strategies differ with respect to the extent a certain rule type is used.

The following section will describe how the configuration rules may be written in propositional logic. The constituents are the variable values called feature variants and logical operators such as NOT ($\neg$), AND ($\wedge$), OR ($\vee$) and IMPLIES ($\rightarrow$). Exclusions declare that for example the feature variant "19 inch tyre" cannot be combined with feature variant "21 inch wheel". The formalized definitions of configuration rules are:

> *Let X be the set of feature families (variables)* $X = \{x_1, x_2, \ldots, x_N\}$, *where N is the number of feature families. Let D be the set of corresponding feature variants (domains)* $D = \{D_1, D_2, \ldots, D_N\}$ *such that* $x_i \in D_i$ *and* $D_i = \{a_1, a_2 \ldots, a_M\}$ *where M is the number of feature variants for the set* D_i.

Exclusion: *Let the scope S be defined as feature family indices in a restriction. An exclusion is a constraint of the form:*

$$\neg \bigwedge_{i \in S} x_i = a_i, \text{ where } a_i \in D_i \tag{1}$$

Inclusion: *An inclusion is a constraint of the form:*

$$x_i = a_i \Rightarrow x_j = a_j, \text{ where } x_i \in D_i,\ x_j \in D_j \text{ and } i \neq j. \tag{2}$$

Product model authorization: *Let C be an arbitrary positive integer. Let the variable describing the product model be denoted y, with $y \in P$ and $P = \{ p_1, p_2 \ldots, p_L \}$ where L is the number of product models. The product model authorizations for product model p_i for feature family x_k is a constraint of the form:*

$$y = p_i \Rightarrow \bigvee_{j=1}^{C} x_k = a_j, \text{ where } p_i \in P \text{ and } a_j \in D_k \tag{3}$$

Van Veen described the maintenance benefit of using item usage rules for translating product specification using features into bill-of-materials, hence he used the definition "item specification" [9]. Vehicles have a high number of allowed bill-of-materials, and it according to Veen it is more efficient to use item usage rules describing a product family instead of manage every single bill-of-material separately. The allowed vehicle configurations are defined by the variant combination rules, while the item usage rules populate allowed vehicle configurations with items.

Item usage rule: *Let the scope S be defined as the feature family indices for the feature variants in an item usage rule. Let B be the complete set of items with $B = \{b_1, b_2, \ldots, b_K\}$, where K is the number of items. The item usage rule to the item b_j is the constraint of the form:*

$$\bigwedge_{i \in S} x_i = a_i \Rightarrow b_j, \text{ where } a_i \in D_i \tag{4}$$

The described automotive information model is fairly limited since it is only using logic operators and not the mathematical operators, e.g. {>, +} as in [8]. The authoring and verification methods that are going to be described in this paper are therefore only valid within the automotive industry and possibly for the business production strategy "assemble-to-order" [10].

3 Research method

This desired result of his study is formalization of the methods used when authoring and verifying configuration rules. The stated research questions with this motivation are:

RQ1: How are configuration rules authored and which variations exist?

RQ2: What are the strengths and weaknesses of different authoring methods?

RQ3: How are missing/incorrect configuration rules detected?

RQ4: What are the strengths and weaknesses of the verification methods?

The research questions were studied at three automotive original equipment manufacturers, which are all large enterprises according to EU definitions [11]. The companies' Product Data Management systems, henceforth PDM systems, for managing the product structure have been developed in-house. Development of variant-rich products, together with a long experience of the PDM systems, makes the companies suitable for studying challenges when authoring and verifying configurations.

3.1 Data collection methods

The interview sessions included interviewees' demonstrations of authoring and verification methods. Documents were also studied, i.e. the guidelines for how to update the product structure. Also, the product structure itself was very useful to study when evaluating the findings. It may therefore be concluded that multiple methods have been used to validate the findings.

3.2 Interview strategy

In total, 20 semi-structured interviews were conducted, which lasted approximately 2 hours each. The interviews were carried out by one or two researchers together with one employee from one of the automotive companies. The interviewees were equally distributed from the roles:

- Design engineer with >20 years experience of the PDM system;
- Design engineer with <5 years experience of the PDM system;
- Product structure specialist with focus on item usage rules;
- Product structure specialist with focus on variant combination rules.

An initial analysis based on the results from four interviews was reviewed by the industrial reference group, consisting of representatives from the product structure specialists, and suggestions for modifications to the interview guide were agreed upon.

4 Results

The results and conclusions were presented in a workshop where all automotive companies participating in the study were attending. The following sections contain the study's results in subsections Role activities, Authoring instructions, Visualization of item usage rules and variant combination rules, Authoring variations and Verification methods.

4.1 Role activities

The interviewees were asked how many hours that were spent on reading, authoring and verifying variant combination rules and item usage rules. The design engineers spend about the same hours independently of experience, in average around 5 hours/week, and the time is usually equally distributed between variant combination rules and item usage rules. There are two types of product structure specialist. Either occupied full-time on reviewing the request of variant combination rules modifications, or occupied full-time reviewing the item usage rules modifications. The later type spends the time equally between item usage rules and variant combination rules.

4.2 Authoring instructions

The instructions for authoring configuration rules were found both from the interviews and the guidelines for how to update the product structure. The recommended practice is at the studied companies to author “as short rules as possible”, and to use the replace functionality as much as possible. The length of an item usage rule or a configuration rule is defined as the number of feature variants used in a single rule. The automotive industry suffers from enormous amount of configuration data, which motivates the need of keeping the rules as short and as few as possible. The use of the replace function is due to the traceability when updating the configuration rules. The risk with using the replace function is the sometimes insufficient analysis of the variant combination rules. The variant combination rules are constantly changing which may result in necessary modifications to the existing rules sets. The next section is about how the variant combination rules and item usage rules are displayed.

4.3 Visualization of item usage rules and variant combination rules

The next two subsections are describing the display of item usage rules respectively the variant combination rules. The item usage rules and the variant combination rules are in the automotive industry displayed in different views in the PDM system, and sometimes not even stored in the same IT system. They are also used to a different extent by different roles.

4.3.1 Matrix versus list of item usage rules

At the studied automotive companies, the item usage rules are presented using two variants of visualization formats, both as a matrix and as list, see Fig. 3. The 18INCHTYRE, 20INCHTYRE, STDWHEEL and SPAREWHEEL are feature variant codes. The item usage rule matrix contains crosses which mean that these feature variants are included in item usage rules. The item usage rule is a logic expression for when a certain item should be used. The first row of the item usage rule matrix is equivalent to the first row in the item usage rule list. 18INCHTYRE and 20INCHTYRE are the feature variants from the same feature family. STDWHEEL and SPAREWHEEL are also the feature variants from the same feature family. The length of item usage rule for ITEM002 is 2, equal to the number of crosses in the second row of the item usage rule matrix. The example shown is a illustrative simplified description of the visualization of item usage rules which holds for all three studied automotive companies, but the real industrial examples includes of course more tyre items and more feature variants in the item usage rules. The benefit of using the matrix format is especially beneficial when comparing item usage rules with many feature variants.

Item usage rule list:

IF(18INCHTYRE)THEN(ITEM 1)
IF(20INCHTYRE & STDWHEEL)THEN(ITEM 2)
IF(20INCHTYRE & SPAREWHEEL)THEN(ITEM 3)

Item usage rule matrix:

			FEATURE VARIANTS:				
	ID:	*Description:*	18INCHTYRE	20INCHTYRE	STDWHEEL	SPAREWHEEL	*Length:*
ITEMS:	ITEM001	Tyre	x				1
	ITEM002	Tyre		x	x		2
	ITEM003	Tyre		x		x	2

x = feature variant included in item usage rule

Figure 3 Item usage rule list as well as item usage rule matrix for three tyres.

4.3.2 List of variant combination rules

At the three studied automotive companies, the variant combination rules are presented as lists, see Fig. 4. The variant combination rules consist of product model authorizations (declaration of allowed feature variants for product models), restrictions (using NOT operator) and inclusions (using IF-THEN operator for feature variants).

List of variant combination rules:
Product model authorization: IF(Model X) THEN (STDWHEEL OR SPAREWHEEL)
Restriction: NOT(18INCHTYRE & STDWHEEL)
Inclusion: IF(18INCHTYRE) THEN(SPAREWHEEL)

Figure 4 List of variant combination rules.

4.4 Authoring variations

All the studied companies have all three types of variant combination rules, but there is a difference with respect to the extent the different types are used. However, even though there are some differences in how variant combination rules are used, the main difficulty still holds since it is how to combine the variant combination rules with the item usage rules. This difficulty is also one of the reasons to why authoring variations exist, as there is a potential of using an overlap between the two classes of rules.

The most common authoring method is to use the replace function, but then there are three variations in how to author configuration rules identified. These will be described in the following subsections, where possible with the formal definition followed by an example and discussion of strengths and weaknesses. It should be underlined that the methods' definitions do not provide any instructions for how they may be implemented in IT applications. Several important evaluation criterions for authoring methods were found from the initial four interviews:

1. Time to find (starting to search → finding);
2. Time to interpret (finding → using);
3. Time to maintain (assumed proportional to update frequency);
4. Time to verify (correctness and completeness checks).

4.4.1 Overlapping documentation

Using overlapping documentation is similar to saying that the candle is red and of wax, when all candles are made of wax. The method's name use the word "overlapping" since the item usage rules repeat some of the information that the variant combination rules states. Overlapping variant combination rules may also occur, and are then repeating information that other variant combination rules states. To avoid overlapping documentation is to use the shortest length of configuration rules. The example in Fig. 5 shows item usage rules for tyres in the matrix format used in one of the studied companies. The example is comparing with and without overlapping documentation. With overlapping documentation the item usage rule for the first ITEM001 is using both 18INCHTYRE and SPAREWHEEL, while without overlapping documentation it is only 18INCHTYRE. For ITEM001, the usage of the SPAREWHEEL is not necessary because of the restriction stating NOT(18INCHTYRE & STDWHEEL).

Item usage rule matrix:

FEATURE VARIANTS:

ITEMS: *ID:*	*Description:*	18INCHTYRE	20INCHTYRE	STDWHEEL	SPAREWHEEL	
ITEM001	Tyre	x			x	With overlapping documentation
ITEM002	Tyre		x	x		
ITEM003	Tyre		x		x	
ITEM001	Tyre	x				Without overlapping documentation
ITEM002	Tyre		x	x		
ITEM003	Tyre		x		x	

Feature variant combination rule list:
NOT(18INCHTYRE & STDWHEEL)

x = feature variant included in item usage rule

Figure 5 Item usage rules with and without overlapping documentation due to variant combination rules.

Using overlapping documentation does not prevent vehicles from being correctly built, but avoiding overlapping documentation is one method for reducing the length of rules and to show that the configuration rules have been analyzed which is beneficial during the verification task. Using the example in Fig. 5, avoiding overlapping documentation shows that ITEM001 is covering all allowed vehicle configurations with 18INCHTYRE. However, with overlapping documentation there seems to be an item missing for the 18INCHTYRE and STDWHEEL. Due to less data to manage, some product structure specialists are claiming that the time is also low for interpreting the item usage rules when avoiding overlapping documentation, see Fig. 6. However, avoiding overlapping documentation means using fewer feature variants for the item usage rules, which makes the item usage rules more difficult to interpret and find for design engineers.

	Evaluation for avoiding overlapping documentation	
	Design engineers	Product structure specialists
Time to interpret	High	Low
Time to maintain	-	-
Time to find	High	-
Time to verify	-	Low

Figure 6 Evaluation of strictly avoiding overlapping documentation in terms of time consumption.

The formal definition of overlapping documentation is presented in propositional logic in formula (5). The formula states that the left hand side is equivalent to the right hand side. The check if an item usage rule or a configuration rule is authored with overlapping documentation may be done by using formula (5) together with e.g. SAT solver.

> ***Overlapping documentation:*** *Let the scope T be the feature variants of an item usage rule, and let the scope S be another set of feature variants. The scope T is an overlapping documentation if the following statement is valid:*

$$\bigwedge_{i \in S} x_i = a_i \Leftrightarrow \bigwedge_{i \in T} x_i = a_i, \; where \; S \subset T \qquad (5)$$

Formula (5) is also valid for variant combination rules, since this would only negate both sides of the equivalence.

4.4.2 High-level feature variants

Using high-level feature variants reduces the number of configuration rules. It is similar to saying that the feature family "outfit colour" is black, instead of saying that the "trouser colour" is black, the "sweater colour" is black and the "shoe colour" is black. In Fig. 7, use of high-level feature variant STDWHEEL results in 1 item usage rule, compared to 2 item usage rules when not using the high-level feature variant. The new feature family with variants LOW, BASIC and HIGH DURABILITY describes the the tyre characteristics. The equivalence between with and without usage of high-level feature variant is in this example due to the variant combination rules.

Figure 7 Item usage rules for tyres with and without use of high-level feature variant STDWHEEL.

Item usage rule matrix:

FEATURE VARIANTS:

ITEMS: *ID:*	*Description:*	18INCHTYRE	20INCHTYRE	STDWHEEL	SPAREWHEEL	LOW DURABILITY	BASIC DURABILTY	HIGHDURABILITY	
ITEM002	Tyre		x	x					Use of high-level feature variants
ITEM002	Tyre		x				x		Without use of high-level feature variants
ITEM002	Tyre		x					x	

x = feature variant included in item usage rule

Feature variant combination rules list:

IF(STDWHEEL) THEN (BASIC DURABILITY or HIGH DURABILITY)

One of the difficulties with using high-level feature variants is that the relations are not at all studied companies explicitly documented in the PDM system. High-level feature variants may instead be found from analyzing variant combination rules. However, the high level feature variants were appreciated by product structure specialists who are constantly suffering of enormous amount of data, see Fig. 8. There is no clear opinion from the design engineers since the usage of high-level feature variants gives various effects in different cases.

	Evaluation for using high-level feature variants	
	Design engineers	Product structure specialists
Time to interpret	-	Low
Time to maintain	-	Low
Time to find	-	Low
Time to verify	-	-

Figure 8 Evaluation of using high-level feature variants in terms of time consumption.

It is possible to define high-level feature variants with propositional logic:

> ***High-level feature variants:*** *Let the scope S be the indices for a set of feature variants from D_k, with $S \neq \{0\}$. The feature variant a_i is a high-level feature variant compared to a_j with $j \in S$ if the following statement is valid:*

$$x_i = a_i \Rightarrow \bigvee_{j \in S} x_k = a_j, \text{ where } i \neq k \tag{6}$$

4.4.3 Building blocks of item usage rules

Using consistent selection of feature variants for the item usage rules may create small "building blocks", which then may be used when allowed according the variant combination rules. The building block may not necessarily avoid overlapping documentation, but aims to have a fixed number of feature variants, see Fig. 9. This method is by far the most used authoring method. The new feature variant codes are FAMILY VERSION and SPORT PACKAGE which are only used without using the building-block method. The equivalence with and without the usage of the building block method in this example is not proven by presenting the variant combination rules.

Figure 9 Item usage rules for tyres with and without use of building block method, here without the necessary variant combinations for proving equivalence with and without using the method.

Item usage rule matrix: FEATURE VARIANTS:

ITEMS: *ID:*	*Description:*	FAMILY VERSION	SPORT PACKAGE	18INCHTYRE	20INCHTYRE	STDWHEEL	SPAREWHEEL	LOW DURABILITY	BASIC DURABILITY	HIGH DURABILITY	
ITEM001	Tyre			x		x					Using building-block method
ITEM002	Tyre				x	x					
ITEM003	Tyre				x		x				
ITEM001	Tyre		x	x							Without using building-block method
ITEM002	Tyre				x	x					
ITEM003	Tyre	x			x			x			

x = feature variant included in item usage rule

The item usage rules and variant combination rules are as independent as they can be, which results in item usage rules requiring low update effort, both by design engineers and product structure specialists, see Fig. 10. Independent means that no variant combination rules analysis is required when authoring the item usage rules. Another aspect is that the design engineers search and find the item usage rules fairly easy when e.g. all tyres are documented with either STDWHEEL or SPAREWHEEL. Concerning the formal definition of this method, the only criteria is a consistent and minimized set of feature families used for an item usage rule set. The method is decreasing the time consumption for the verification activity, since it becomes easier to compare similar exclusions or similar item usage rules.

	Evaluation for building-block method:	
	Design engineers	Product structure specialists
Time to interpret	-	-
Time to maintain	Low	Low
Time to find	Low	-
Time to verify	Low	Low

Figure 10 Evaluation of the building-block method in terms of time consumption.

4.5 Verification methods

Some of the authoring methods described have a positive impact on the verification efficiency. However, the methods for verification using manual inspection are not found to be documented at the studied companies. The verification tasks have been divided into two sections depending on if they are investigating the allowed vehicle configuration or the population of items on these.

4.5.1 Verification of allowed feature variant combinations

The verification of allowed feature variant combinations is most commonly done by the product structure specialist, but may also be done by the responsible design engineer. Either the variant combination rules are analyzed by reading their formulation, or the allowed feature variant combinations are generated. As is stated in [9], the correctness of each configuration rule may be validated separately, but in large sets of variant combination rules it can be very difficult to interpret the “implicit rules”. The implicit rules are constraints which are not explicitly expressed by a rule, but which follow from a combination of explicitly defined rules. The generated allowed feature variant combinations take both explicit and implicit rules into account. Several interviewees mentioned that they found the generated allowed feature variant combinations easier to read, but this verification method is not mandatory and very few design engineers use it. One of the reasons may be that it is difficult to find the explanations to why (which variant combination rules) a feature variant combination is not allowed without IT system support or other deficiencies in the functional core of the IT system. Another reason to why the verification method is not used may also be the interface since the allowed feature variant combinations does not show any information about item usage rules or items.

The allowed feature variant combinations may be compared to the design engineers' knowledge about which feature variant combinations should be allowed and which should not, see Fig. 11. The first row is the allowed feature variant combination 18INCHTYRE & STDWHEEL & BASIC DURABILITY according to the variant combination rules. The allowed feature variant combinations show the effect of all variant combination rules, and may be easier to analyze instead of looking at product model authorizations, exclusions and inclusions separately. If there are allowed feature variant combinations that should be restricted, then there are feature variant combination rules missing and vice versa.

FEATURE VARIANTS:

Allowed feature variant combination list:	18INCHTYRE	20INCHTYRE	STDWHEEL	SPAREWHEEL	LOW DURABILITY	BASIC DURABILITY	HIGH DURABILITY
Allowed feature variant combination 1	x		x			x	
Allowed feature variant combination 2	x		x				x
Allowed feature variant combination 3		x	x			x	
Allowed feature variant combination 4		x	x				x
Allowed feature variant combination 5		x		x	x		
Allowed feature variant combination 6		x		x		x	
Allowed feature variant combination 7		x		x			x

Variant combination rule list:
NOT(18INCHTYRE & SPAREWHEEL)
IF(STDWHEEL) THEN (BASIC DURABILITY or HIGH DURABILITY)

x = feature variant included in allowed feature variant combination

Figure 11 The allowed feature variant combinations and the variant combination rules.

4.5.2 Verification of allowed items

The verification of allowed items is the activity to make sure that every allowed feature variant combination is populated with the correct items. Typical errors show up either as vehicle specifications missing necessary items, or items not used at the assembly line. Assuming correct variant combination rules from the previous section, it is faulty item usage rules that cause these errors to occur.

The visual verification of allowed items is mainly done by studying item usage rules, but if necessary also the variant combination rules to realize which vehicle configurations that are allowed. In the previous presented Fig. 7, there is an example where it is clear that the item usage rules do not provide enough information for verifying that only one ITEM001 is allowed for every allowed vehicle configuration. It is necessary to know if STDWHEEL is allowed in combination with BASIC or HIGH DURABILITY to realize if multiple items are allowed for the same vehicle configuration. In the example shown, there will always be two ITEM001 for some of the allowed vehicle configuration.

4.6 Discussion of results

At the studied companies, each configuration rule is analyzed if it can be shortened, called avoiding overlapping documentation. This is the method that has shown the clearest discrepancy between design engineers and product structure specialists. However, the by far most common authoring method is to replace what already exists with new rules slightly modified. This is mainly due to the otherwise time-consuming and difficult analysis of variant combination rules. From this discussion, it may be concluded that the main difficulty for design engineers is how to make sure that all types of configuration rules together describes the by product planning department requested and buildable vehicle specifications.

Both the verification of allowed feature variant combinations and allowed items requires the capability to analyze the variant combination rules. As a consequence, it was found that the verifications are primarily conducted by product structure specialists. These findings motivate the need for facilitating the configuration rule analysis by adequate system support.

5 Generalization

The automotive information model used in this paper has been verified to exist at the studied automotive companies and previous paper [6] contains a literature review on the subject of typical automotive information model. This information model contains both feature variants and items, which are describing vehicle configurations by using configuration rules. During both authoring and verification of item usage rules, the main difficulty found was how to make sure that the types of configuration rules together describe the by product planning department requested and buildable vehicle specifications. This difficulty occurs due to the automotive information model, and is then founded on the model's validity which has been proven well-funded. The comparison between the companies is the main strategy for obtaining generalization of the results.

Another similarity between the studied automotive companies is the structure of the PDM system. The item usage rules and variant combination rules are in different views or even different systems, which further make the combination of item usage rules and variant combination rules difficult and therefore preferences of certain authoring methods.

6 Conclusions

The literature review showed that the authoring and verification methods of configuration rules described in this paper are rarely studied. Authoring variations have been identified, where readability is put against compactness and maintainability. Repeatedly arguments for using an interface consisting of a matrix format are presented. We have also shown that the main difficulty is to combine variant combination rules with item usage rules, and the traditional interface to the PDM system consisting of a database viewer should therefore be challenged. With the formalization of the authoring and verification methods, there is a potential for higher degree of automation of these activities which would facilitate the work for both product structure specialists and design engineers. We have shown that the time spent on reading, authoring and verifying configuration rules is significant for design engineers, and full-time job for product structure specialists, which motivates realizing the automation potential and thereby reducing development costs.

7 Future work

Since the different users show different needs when interpreting the configuration rules, it is impossible to verify configuration rules without an analysis support that makes short and few rules more informative and understandable. The methods presented in this paper are essential when developing this analysis support that would facilitate the validation of configuration rules.

Acknowledgment

This work was carried out at the Wingquist Laboratory VINN Excellence Centre within the Area of Advance – Production at Chalmers, supported by the Swedish Governmental Agency for Innovation Systems (VINNOVA). The support is gratefully acknowledged.

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Improving Engineering Change Management with Information Demand Patterns

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Abstract: Among the activities to be performed in the life of products, engineering change management (ECM) can be considered as in particular complex. Many industrial examples show that there is a need for improving robustness and reliability of ECM in practice. This paper contributes to the area by proposing information demand patterns as a means to capture organizational knowledge about the desired information flow in engineering change management. The intention is to avoid wrong decisions, delayed actions and insufficient change implementations in ECM caused by insufficient information supply. The contributions of the paper are (1) the concept of information demand pattern in the context of ECM, (2) the information demand pattern for the role of a "change administrator", and (3) lessons learned from validation.

Keywords: engineering change management, process improvement, enterprise modeling, information logistics, information demand, pattern

1 Introduction

Among the many activities to be performed in the life of products, engineering change management can be considered as in particular complex. Especially in networked organizations, many different partners with complementing competences and distributed responsibilities for different elements of the product, it is crucial to implement changes in the product timely, completely and by including all affected and involved partners. Delayed or insufficient implementation of changes can lead to costly problems of products and affect customer relationships. In order to ease the implementation of well-defined and efficient engineering change management processes, standard processes, like CMII [1], were proposed and tool support has been developed. However, many industrial examples show that there is a need for improving robustness and reliability of engineering change management (ECM) in practice. This paper aims at contributing to the area by proposing information demand patterns as a means to capture organizational knowledge about the desired information flow in engineering change management. The intention is to avoid wrong decisions, delayed actions and insufficient change implementation in ECM caused by insufficient information supply. The contributions of the paper are (1) the concept of information demand pattern in the context of ECM, (2) an actual information demand pattern for the role of a "change administrator" in order to illustrate the concept, and (3) lessons learned from validating this pattern.

The remaining part of the paper is structured as follows: the background for the work from information logistics and enterprise modeling is briefly introduced in section 2. Section 3 presents an industrial case in engineering change management motivating the research. The concept of information demand patterns and the method used for information demand analysis are introduced in section 4. Section 5 presents the information demand pattern for the role of a "change administrator" including the validation activities performed. Conclusions and future work are discussed in section 6.

2 Background

Work from the areas information logistics and enterprise modeling form the background for the work presented in this paper and will be summarized in this section.

2.1 Information Logistics

Accurate and readily available information is essential in decision-making situations, problem solving and knowledge-intensive work. Recent studies show that information overload is perceived as a problem in industrial enterprises [8]. An example of a problem in relation to information overload is, in relation to different roles, to find the right information needed for a work task. It is expected that an improved information supply would contribute significantly to saving time and most likely to improving productivity.

The research field information logistics addresses the above mentioned challenge by using principles from material logistics, like just-in-time delivery, in the area of information supply. The main objective of information logistics is improved information provision and information flow. The research field explores, develops, and implements concepts, methods, technologies, and solutions for the above mentioned purpose. Contemporary research work in information logistics includes

- a method for information demand analysis in an enterprise context [7],
- patterns of information demand for efficiently constructing solutions [6],
- technologies for matching information demand and content [5],
- applications for networks of automotive suppliers [4] or media industries [3].

2.2 Enterprise Knowledge Modelling

In general terms, enterprise modeling is addressing the systematic analysis and modeling of processes, organization structures, products structures, IT-systems or any other perspective relevant for the modeling purpose [9]. Lillehagen and Krogstie [10] provide a detailed account of enterprise modeling and integration approaches. Enterprise models can be applied for various purposes, such as visualization of current processes and structures in an enterprise, process improvement and optimization, introduction of new IT solutions or analysis purposes.

Enterprise knowledge modeling combines and extends approaches and techniques from enterprise modeling. The knowledge needed for performing a certain task in an enterprise or for acting in a certain role has to include the context of the individual, which requires including all relevant perspectives in the same model. Enterprise knowledge modeling aims at capturing reusable knowledge of processes and products in knowledge architectures supporting work execution [12]. These architectures form the basis for model-based solutions, which often are represented as active knowledge models. [13] identify characteristics of active models vs. passive models and emphasize that “the model must be dynamic, users must be supported in changing the model to fit their local reality, enabling tailoring of the system’s behavior”.

In most methods supporting enterprise modeling or enterprise knowledge modeling, information flow is analyzed as part of the business process. Examples of such methods are EKD [15] and MEMO [16]. With exception of the approach discussed in section 4, methods specifically focusing on information demand analysis do not exist, as confirmed by the survey published in [17].

3 Industrial Case

The proposed information demand pattern, which is presented in section 5 of this paper, is based on work in the R&D project InfoFlow, which includes 6 industrial and academic partners. Within InfoFlow, modelling of information demand was performed in a number of industrial cases in order to collect experiences from various situations and domains. This section will briefly discuss one of these cases in order to show the process of modelling, the organisational setting, and results. The industrial case selected is a sub-supplier to different first-tier suppliers in automotive and telecommunication industries who performs various surface treatment services of metal components. Surface treatment in this context includes different technical or decorative coatings to achieve certain functionality or appearance.

The case had the focus on engineering change management in the production process. The challenge is to handle the continuously incoming change specifications for products manufactured for many different OEMs in the automotive industry. Not implementing the changes in time would lead to products with wrong characteristics and economic consequences. After modelling of the change management process and its relation to the production processes, an information demand analysis of a specific part of the ECM process (from quotation to production planning) was performed using the method described in section 4.

The actual modelling, was divided into two main activities, 1) interviews, and 2) a facilitated modelling seminar. In these two activities, the head of quality, sales representative, technical support/technical in-house sales, production planner and two researchers were involved. The main purpose of the interviews was to set the stage and decide the focus for the following seminar. The major purpose of the modelling seminar was to understand the information demand for different roles based on their assignments in the process. The modelling seminar was performed in a participative way where the representatives from the industrial partner were actively involved in the modelling. The modelling was performed on plastic sheets with sticky notes and whiteboard markers. The result from the seminar has been used by the head of quality to elucidate and share knowledge among the employees about certain dimensions in the change management process. The models have served as an instrument to develop shared knowledge amongst roles at the industrial partner about different aspects of the practice in terms of information demand and information flow.

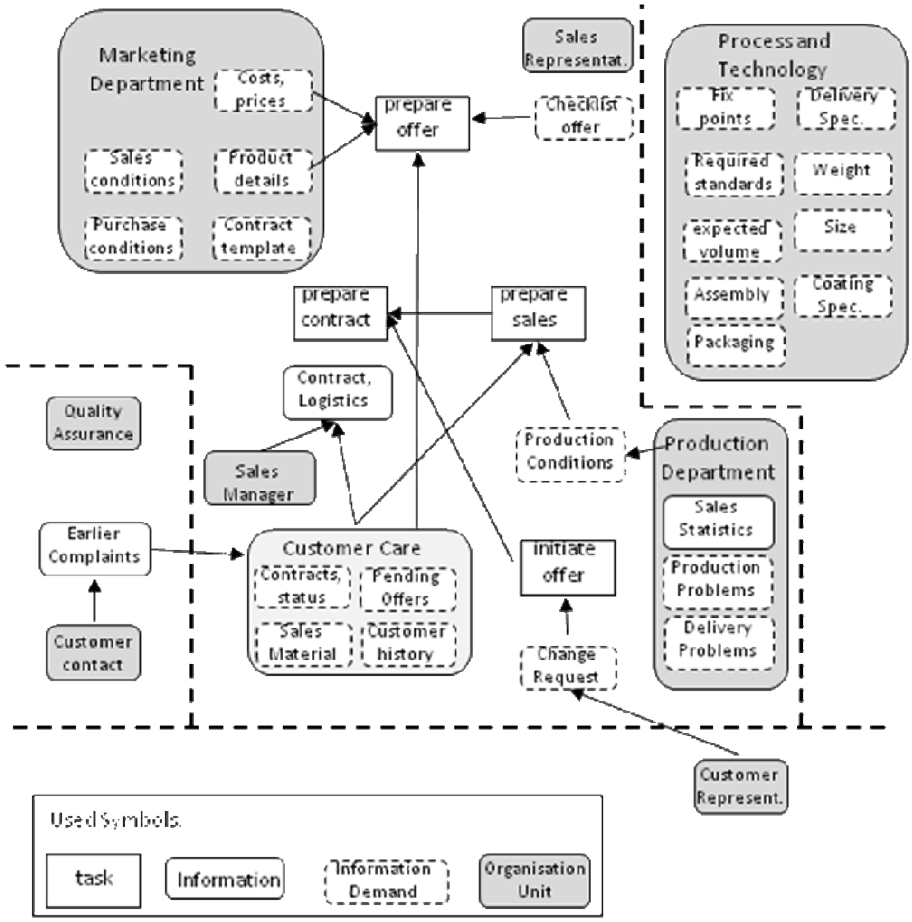

Figure 1: Excerpt of an information demand model from the Proton case.

Figure 1 is part of an information demand model developed in the Proton case focusing on the sales process (from quotation to production planning). It shows the different departments involved (production, marketing, process and technology, and sales) and illustrates their information demand and what information is produced. The whole process is initiated by a change request from a customer representative (depicted at the lower left corner on the right hand side).

4 Information Demand Analysis and Patterns

This section introduces the concept of information demand patterns (section 4.2) and a method for analyzing the information demand of organizational roles in enterprises (section 4.2).

4.1 Information Demand Analysis

The understanding and definition of the term information demand used in this paper is based on empirical work performed during 2005-2007, which also contributed a deeper understanding of how information is used with regards to work-related tasks. Information demand will be used throughout this paper with the following meaning:

"*Information Demand is the constantly changing need for relevant, current, accurate, reliable, and integrated information to support (business) activities, when ever and where ever it is needed.*" [14, p.59]

Furthermore, the empirical investigation confirmed the conjecture that information demand of a person is based on the roles and tasks this person has: "*Information demand depends on the role and tasks an entity has within a larger organization. If the role and/or the tasks change, so too will the demand".* This role-centric perspective with task and responsibilities as primary characteristics has been the starting point for developing the method for information demand analysis and the approach of demand patterns.

Understanding the information demand of an organization is a complex undertaking and has as such to be broken down in several interconnected phases that can be applied in a sequential and iterative manner depending on the given problem and desired outcomes. A method for information demand analysis was developed in order to supports this analysis based on a well-defined method notion and overall framework [18]. According to this method, the process of analyzing information demand starts with scoping the area of analysis, includes information demand context modeling, analysis and evaluation, and concludes in the application of the results in suitable software engineering and business process reengineering activities implementing an improved information flow.

Most of the phases in the process as well as the activities within them are performed in a participative manner in the sense that they should be performed in cooperation with stakeholders in the enterprise under consideration. Furthermore, each phase has a clearly defined list of prerequisites and expected outcomes as described in the method handbook [11]. The different phases have the following main characteristics:

Scoping: Scoping is the activity of defining the area of analysis and is done with the purpose of selecting the part of an organisation or process to analyse with respect to information demand as well as identifying the individuals providing the necessary background information during the continued process of analysing.

Information Demand Context Modeling: The main purpose of this phase is to identify the basic information demands based on the core concept of information demand context, i.e. which role needs to do what tasks and what does this require in terms of resources.

ID-Context Analysis and Evaluation: Once the context related information is gathered this has to be analysed (and if necessary clarified and refined) and represented in a format useful for continued work. In addition to developing models, this step also allows for comparing the results to existing enterprise information if available. During this phase a choice has to be made whether or not the analysis should be continued and if so how in terms of what refinements to focus on.

Representation and Documentation: As the different analysis phases produce models and documents expressed in different notations the purpose of this phase is to collect and combine the results into a unified coherent representation that can be used to communicate the information demands as well as utilise them in activities aimed at improving information flow.

4.2 Information Demand Patterns

The general idea of information demand patterns (IDP) is similar to most pattern developments in computer science: to capture knowledge about proven solutions in order to facilitate reuse of this knowledge. In this paper, the term information demand pattern is defined as follows: *An information demand pattern addresses a recurring information* *flow problem that arises for specific roles and work situations in an enterprise, and presents a conceptual solution to it.*

An information demand pattern consists of a number of essential parts used for describing the pattern: pattern name, organisational context, problems addressed, conceptual solution (consisting of information demand, quality criteria and timeline), and effects. These parts will be described in the following. An example for an actual pattern is presented in section 5.

- The *pattern name* usually is the name of the role the pattern addresses.
- The *organisational context* explains where the pattern is useful. This context description identifies the application domain or the specific departments or functions in an organisation forming the context for pattern definition.
- The *problems* of a role are identified. The tasks and responsibilities a certain role has are described in order to identify and discuss the challenges and problems, which this role usually faces in the defined organisational context.
- The *conceptual solution* describes how to solve the addressed problem. This includes the i*nformation demand* of the role, which is related to the tasks and responsibilities, a t*imeline* indicating the points in time when the information should be available, and q*uality criteria* for the different elements of the information demand. These criteria include the general importance of the information, the importance of receiving the information completely and with high accuracy, and the importance of timely or real-time information supply.
- The *effects* that play in using the proposed solution are described. If the needed information should arrive too late or is not available at all, this might affect the possibility of the role to complete its task and responsibilities. Information demand patterns include several kinds of effects: potential economic consequences; time/efficiency effects; effects on increasing or reducing the quality of the work results; effects on the motivation of the role responsible; learning and experience effects; effects from a customer perspective.

The above parts of a pattern are described in much detail in the *textual description* of the pattern. Additionally, a pattern can also be represented as a *visual model*, e.g. a kind of enterprise model. This model representation is supposed to support communication with potential users of the pattern and solution development based on the pattern.

5 Information Demand Pattern "Change Administrator"

5.1 The Pattern

In order to contribute to ECM and to illustrate the approach presented in section 4, the information demand pattern "change administrator" was selected. The pattern was developed in the context of the industrial case introduced in section 3, a second case from the same project infoFLOW and recommendations for engineering change management from CMII [1]. The enterprise knowledge models from the two cases and the CMII recommendations were analysed starting from the roles and their relations to processes and infrastructure resources. The initial approach to find recurring roles in the different models was not successful, since many roles were named differently in different organisations. Hence, the focus of the analysis was changed to find reoccurring tasks and responsibilities in the different models, which would indicate a specific information demand.

The tasks of “change administrator” appeared in several models, but sometimes were called “project manager” for change projects or the tasks were included in the responsibility area of the “product manager”. We decided to use the term “change administrator”, since the CMII standard uses this term. The information demand of what in the following will be called the role “change administrator” was derived from the textual descriptions accompanying the enterprise models and the descriptions developed in the modelling process. The information demand pattern is presented with the textual representation only.

The textual description follows the structure introduced in section 4.2. The first element is the context where the pattern is useful:

Context:

The context for this pattern is configuration and change management in manufacturing industries, in particular industry sectors with complex physical products. Changes in products, product parts or installed systems are usually initiated by change reports or enhancements requests. Systematic handling of such requests requires coordination of decision making and implementation, often in a team with members from many different engineering disciplines. The role responsible for coordinating change request for a specific product, product part or system is often called change administrator. […] The pattern describes the information demand typically experienced by the role change “administrator”.

The pattern is supposed to be useful for enterprises developing and producing physical products with different variants and various released configurations. The pattern focuses on the change administrator, i.e. it does not include change implementation and change audit. In enterprises integrating change administration, implementation and audit in the same role, the pattern can be used as starting point, but needs to be extended.

The next part is the problem addressed by the pattern:

Problem:
The pattern addresses the general problem of delayed decisions, redundant activities and inconsistent data in engineering change management and the resulting product or quality problems. This includes the following problems, which were observed by practitioners in engineering change projects:

- *Different problem reports or enhancement requests often are related or originate from the same product characteristic, but this is difficult to detect in the description of the change request. Thus, different change implementation processes for the same cause are initiated. […]*
- *Test results or policy changes, possibly from other business areas of the company using components from the same supplier, indicate that the use of the component or supplier should be changed. This information is not reaching the change administrator, as this role is not part of the respective work process or organization unit where the relevant information is produced.[…]*

It follows the information demand, which is based on the tasks and responsibilities of the role under consideration:

Information Demand
The information demand is based on the tasks and responsibilities of the role. The tasks of the change administrator include

- *Responsibility: to manage all change requests directed to the product or product part in the change administrator's responsibility area (a) according to the enterprise quality standards (b) with economic resource use and (c) priority-driven change implementation*
- *To initiate up-front planning and decision making*
- *To ensure completeness and integrity of the data*
- *To coordinate decision making about feasibility and priority, planning and implementation of the change requests*
- *[…]*

The information demand of the role material responsible consists of:

- *To receive all* ***problem reports*** *or enhancement requests regarding the product or product part in the change administrator's responsibility area*
- *To get all information about* ***changes in company-internal policies*** *or in public laws and regulations […]*
- *To receive all information about* ***status changes*** *of all on-going change projects*
- *To have access to information about the* ***released configurations*** *for all variants*
- *To have access to the documentation of all* ***completed change processes***
- *To receive all* ***pertinent information*** *regarding the problem, like description, initiator, affected item, etc.*
- *[…]*

Information Demand	***General importance***	***Accurate***	***In real time***	***complete***
Problem reports	*decisive*	*Decisive*	*high*	*decisive*
Policy, law, regulation changes	*high*	*High*	*high*	*decisive*
Status changes	*decisive*	*High*	*Deci-sive*	*high*
Released configurations	*decisive*	*Decisive*	*high*	*decisive*
Completed change processes	*high*	*High*	*high*	*high*
[…]	*[…]*	*[…]*	*[…]*	*[…]*

Table 1: Quality criteria for example pattern

The quality criteria for the above information demand information uses three levels:

- Decisive: you can't manage without this information
- High: it is very important to have, but in worst case you could complete the task without
- Nice to have: you will manage without this information, but this will affect the result

For each pattern, the quality criteria are summarized in a table, which includes the information demand (left column), the general importance of this information, and the importance to get the information accurately, as soon as possible and completely. Below is an extract of the table for the example pattern:

The effects of not receiving the needed information or of receiving it too late are described in a short text and in a table. We will only include an excerpt of this text and table (table 2) due to space limitations:

Effects

If the needed information should not be available or arrive too late this will have effects on the work of the material specification responsible:

- *Economic effects: the economic consequences could be*
  - *Increased costs by implementing the related change requests twice*
  - *Increased cost for the component or product, reducing the profit margin for the supplier*
  - *Increased level of investment in production equipment*
- *Time/efficiency of the task: engineering change management will need much more time and will be less efficient. An example is*
  - *When changing an insufficient product characteristic, one extra test loop is required for the validation of the complete product*
- *Quality improvement or reduction: the quality of the products is positively or negatively affected by this information. Examples are:*
  - *Late reinforcements of the product, due to late completion of change implementation, might result in reduced performance*
- *[…]*

	Economic effect	***Time efficiency***	***Quality effect***	***[…]***
Customer Change Requests	*high*	*High*	*high*	*[…]*
Complaint from own production	*high*	*High*	*high*	*[…]*
[…]	*[…]*	*[…]*	*[…]*	*[…]*

Table 2: Summary of effects for example pattern

The above matrix shows the relations between information and effects. The following categories were used in the table:

- Low: The impact of any missing/inaccurate/late information is low.
- Moderate: The impact of any missing/inaccurate/late information is limited.
- High: the impact of any missing/inaccurate/late information may be considerable.

The timeline and the visual model of the information demand pattern are not included in the paper due to space restrictions.

5.2 Pattern validation

The validation of the information demand pattern approach has to be divided into validation of the approach as such (including the structure of information demand patterns and the utility of the approach) and validation of the actual pattern presented as an example in the previous section. The validation task was so far mainly performed in a group of domain experts with five industrial representatives and four researchers.

The pattern structure and definition presented in section 4.2 was discussed and refined in so far 3 iterations. Each iteration included the improvement of the approach as such and the development of one new pattern with the improved approach. The developed patterns so far include the roles “responsible for proposal writing” in academic organizations, “team manager for preparing a quote” and “material specification responsible” in manufacturing enterprises, “responsible for branding” in a service organization, and the pattern for “change administrator” introduced in this paper. The different iterative development steps did not change the structure of patterns significantly, but mainly contributed to a refinement of the level used for describing the quality criteria, the effects and the timeline.

The pattern “change administrator” as such was validated in three steps:

- The first version was presented, discussed and refined during an infoFLOW project meeting. This included a walkthrough the visual model and a in detail discussion of the textual description
- The revised version was presented to an industrial expert in the field who proposed changes and improvements, primarily regarding the effects to be expected and the required information quality.
- This refined version was again discussed in a project meeting.

5.3 Related work

Engineering change management has been subject of many research activities during the last decade, which are manifested in proposals for standardization, such as CMII [1] or in work addressing deployment and implementation of selected aspects of ECM, such as [2]. Information flow problems and communication problems in ECM, product design and production planning have been observed before (see, e.g. [19]). Most solution proposals in this area use process improvement or work re-organization as their main element.

Concepts, methods and technologies for identifying, capturing and reusing organizational knowledge have been subject of research in organizational sciences and industrial engineering since more than two decades. Patterns of organizational knowledge are contributing to this area. Selected recent developments are:

Work from van der Aalst and colleagues [20] in the field of workflow patterns. Van der Aalst et al. proposed patterns of workflow including different perspectives like control, data flow, resources or operational aspects. These patterns focus on the flow of work but do not represent the information flow or information demand perspective.

The Patterns4Groupware project maintains a comprehensive online catalogue of patterns for groupware. Each pattern provides proven solutions for a specific groupware problem, and is expressed independently from the underlying technology [21]. These patterns cover general tasks of cooperation and communication in the collaboration process, but not the specific information demand aspects of roles involved.

The Liberating Voices! Project [22] uses patterns and a pattern language to provide a “knowledge structure” that represents the collective knowledge and wisdom of the community. The goal is to develop pattern languages supporting the community members to design, develop, manage and use information and communication systems. The project selected approx. 240 patterns published on the project website and organized in themes and categories. Information demand is not a subject of these patterns.

Furthermore, in the context of our own work, we proposed the use of task patterns for capturing knowledge about best practices in executable knowledge models. The term “task patterns” was introduced for these adaptable models, as they are not only applicable in a specific company, but are also considered relevant for other enterprises [23].

6 Summary and Future Work

Starting from work on information demand modelling and from an industrial case in engineering change management, the paper proposes an information demand pattern for the role of a change administrator in an enterprise’s ECM process. The change administrator role is responsible for coordinating all change requests in his area of responsibility, in order to avoid *the general problem of delayed decisions, redundant activities and inconsistent data in ECM and the resulting product or quality problems.* This paper aims at contributing to the area by proposing information demand patterns as a means to capture organizational knowledge about the desired information flow in engineering change management. This approach differs from all approaches using process optimization or definition of best practice standards by putting the information demand into focus, not the activities to be implemented. The approach of using information demand patterns was found useful for processes with many different roles involved and at the same time many exceptions and ad-hoc decisions.

The main limit of the research presented here is the missing evaluation of the approach in an industrial setting. The information demand pattern has been implemented in an adapted version in the industrial case considered in section 3, but this implementation has not yet been thoroughly evaluated. It would be worthwhile and interesting to both test the proposed information demand approach in more real-world cases and to compare different industrial domains, in particular aiming at non-domain specific support for information flow. However, this would also require a different research design with preferably an additional focus on organizational learning.

Acknowledgements

Part of the work presented in this paper was supported by the Swedish KK-Foundation, project infoFLOW-2 (grant # 2009/0257), and by the Swedish Foundation for Internationalisation in Higher Education and Research, project DEON (grant # IG 2008-2011).

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Chapter 2
PLM Implementation

PLM implementation roadmap for Divertor Test Platform of ITER fusion energy program

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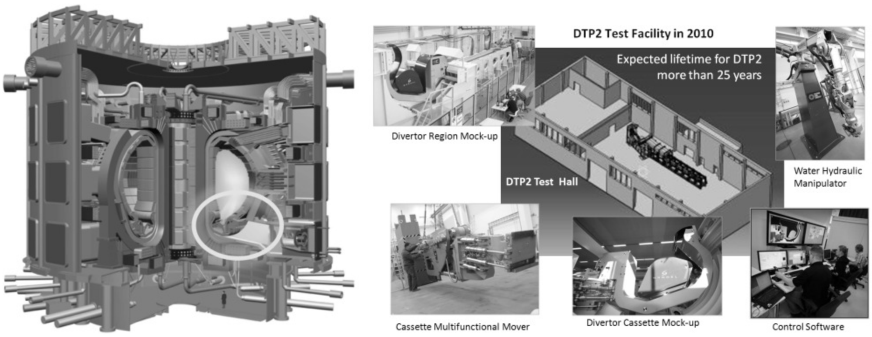
Abstract: ITER intends to prove the viability of fusion as an energy source, and to collect the necessary data for the design and subsequent operation of the first electricity-producing fusion power plant. DTP2 facility is supporting the ITER project. It is a full scale test facility intended for testing, demonstrating and refining the remote handling equipment designs with prototypes. PLM landscape of DTP2 covers both product type and product in use data and information management. DTP2 has a very long life-cycle of several decades. It is a complex high-tech mechatronic system consisting of many engineering disciplines. In order to enhance systematic support of DTP2 activities, a PLM platform development project was launched. Aim of this paper is to introduce the PLM platform. As results from the platform project proposed PLM process model, mechatronic product data model, and PLM system architecture framework are introduced.

Keyword: PLM implementation, fusion energy, mechatronic system

1 Introduction

ITER is a large-scale scientific experiment intended to prove the viability of fusion as an energy source, and to collect the data necessary for the design and subsequent operation of the first electricity-producing fusion power plant [1]. DTP2 (Divertor Test Platform 2) facility (Figure 1) is supporting the ITER project. DTP2 is a full scale physical test facility intended for testing, demonstrating and refining the remote handling (RH) equipment designs with prototypes. The facility will also be used for training future ITER RH operators. Effective and efficient remote replacement of the ITER divertor is central to the successful execution of the ITER project. The overriding aim of the DTP2 is to ensure that the cassette movers supplied to ITER during its construction are based on well-matured designs which have benefited from the experience and lessons learnt from the building and operation of a first generation of prototypes. [2], [3]

Figure 1 The ITER fusion reactor and DTP2 facilities



1.1 Motivation and objective

DTP2 is a complex high-tech mechatronic system consisting of many engineering domains like mechanics, electronics, hydraulics, software development, virtual prototyping and virtual reality, and special new technologies like mobile robotics, water hydraulics, remote operation, and machine vision. In current phase of the project, management of the fuzzy front end of product development, including research activities, concept design, simulations, and virtual prototyping, is challenging. Technical and functional requirements for the DTP2 are high, since water-hydraulics driven remote operated system has to be capable for moving 9 ton divertor cassette with few millimeter accuracy and compensate mechanical and hydraulic flexibilities. Virtual engineering (Virtual Reality, computer simulations, FEA, etc.) are utilized in several lifecycle stages: Concept development, engineering design, remote operation, problem solving, visualization, etc. Versions and revisions of virtual simulation models must be managed well. Projects around DTP2 involve a large network of organizations from universities to research institutions and companies. This kind of novel system development needs system engineering approach [4]. Product Lifecycle Management (PLM) is a framework to gain benefits in this kind of system development environment. With PLM it can be secured that right product information is available at right time for different stakeholders during development, engineering, manufacturing, in-test and in-use. Presently there is lack of IT-support for PLM of DTP2 development.

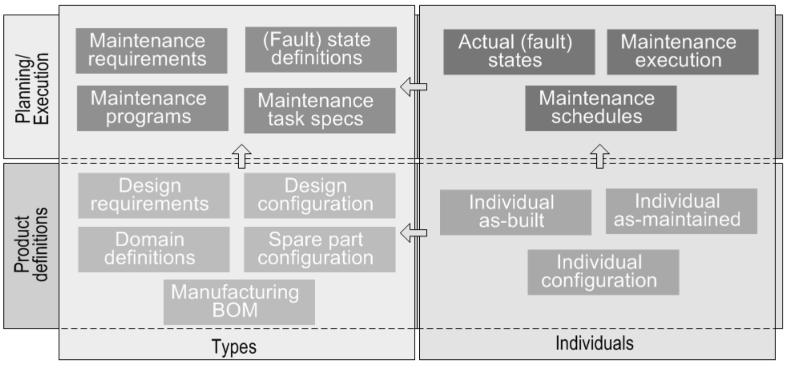
1.2 PLM Approach

Product lifecycle management (PLM) is an integrated, holistic information-driven business approach comprised of people, processes/practices, and technology to all aspects of product's life, from its design through manufacture, deployment and maintenance, see e.g. [5],[6]. Components of PLM include the products themselves, organizational structure, working methods, processes, people, information systems and product data.

From PLM perspective DTP2 is an environment which requires full product lifecycle support (Figure 2), from early development concepts until the in-test, and finally in-use period of the fusion reactor itself. PLM has to support the unique long in-test and in-use timeline of approximately 50 years. Besides the "traditional" PLM aspects (e.g. design configuration and individual configuration) of managing the definitions of product types and individuals, there is an important requirement to manage the information required for planning of execution of the divertor itself (e.g. maintenance programs and maintenance execution). Different product structure configurations and components, as well as simulations and test operations must be traceable during the whole life-cycle of the system. DTP2 will also be utilized in testing, risk analyses, problem solving, and training during ITER commissioning and operation.

History of developing concepts and specifications of DTP2, and testing the DTP2 individual system must be traceable later during the whole life-cycle of the system, since cumulated information will be utilized in the actual ITER reactor construction, operation, maintenance, and problem solving. This requirement is in high importance level simply because of the fact that when the final fusion reactor operates no human can access directly the platform. There are extremely high safety critical requirements to fulfill. Systematic and accurate requirement management and change management processes are essential. From PLM approach point of view, there are also challenges in implementation because conventional PLM installations do not support system engineering of a mechatronic system in best possible way [7] [8].

Figure 2 Illustration of the whole product lifecycle [9]



1.3 Aim of the paper

Aim of this paper is to introduce results from DTP2 PLM platform development project. The PLM –platform maps together PLM related requirements from relevant stakeholders and defines a concept how to harmonize product data and processes. It also forms a base for requirements related to a PLM –system architecture.

2 Methodology and material

2.1 ITER related procedures

Concept design and engineering work that is done at DTP2 shall follow ITER rules. Design tool for mechanical design is Catia V5. Modelling work is done according to ITER CAD-manual, which includes modeling rules and naming rules for 3D-models. Some attributes for 3D-models need to be added also because ITER will store all CAD information under their PLM system. First phase in the concept design process is the gathering of the design input data. Design input data includes requirements for the design task. Source for these requirements is ITER System requirement documents (SRD).

Typically SRD describes system basic configuration and boundaries, design, safety and quality requirements. Applicable codes and standards are also presented in the SRD.

After the collection phase requirements need to be analysed to evaluate their maturity and completeness. Priority of the requirements is defined and classified. Next phase in the system design approach is system concept definition. [10]

2.2 Current DTP2 facility and PLM architecture

Presently the DTP2 facility consists of Divertor Region Mock-up, Divertor Cassette Mock-up, Cassette Multifunctional Mover (CMM), Water-Hydraulic Manipulator, Control Software, Control Room and DTP2 Test Hall (Figure 1).

Current main PLM architecture of DTP2 includes authoring and analysis tools (Dassault CatiaV5, Dassault SolidWorks), software development management system (Subversion SVN), electrical engineering design tool (Eplan), virtual reality software (Dassault Virtools), simulation and analysis software (Dassault Delmia), common office programs, a project management system and a document and quality management system.

2.3 Interviews and workshops

PLM platform requirements specification was created collaboratively with the PLM end users during several interviews and workshops. The interviewees and workshop participants consisted of stakeholders from project management, system engineering, quality and information management departments, and representatives from different engineering disciplines and domains, i.e. mechanical engineers, software developers, electrics engineers, virtual reality and virtual prototyping experts, remote operation personnel, and testing engineers. The interviews and workshops were led by a PLM expert. Based on the requirements specification, a mechatronic product data model and needed PLM processes were defined and modeled using UML-language.

2.4 PLCS standard

PLCS was partially applied in PLM platform definition. PLCS standard (ISO STEP AP 239) supports the product lifecycle management approach. There are also capabilities in PLCS that support system engineering approach. So called breakdown structures and relation between them support the system engineering method by utilizing functional breakdowns, system breakdowns, physical breakdowns, and actual product structure. [11]

3 Results

The created PLM –platform defines common understanding of PLM framework, proposal for management how to proceed with PLM development, defines roadmap and key development areas, defines PLM –related requirements, defines common PLM –processes, defines common product data model, defines a PLM system architecture framework, and defines needs for legacy data harmonization/consolidation

3.1 PLM Platform requirements

In Table 1 the main requirements for the DTP2 PLM platform are listed. They are divided into general and DTP2 special requirements, as well as engineering domains based requirements. All requirements were gathered in the DTP2 PLM platform interviews and workshops.

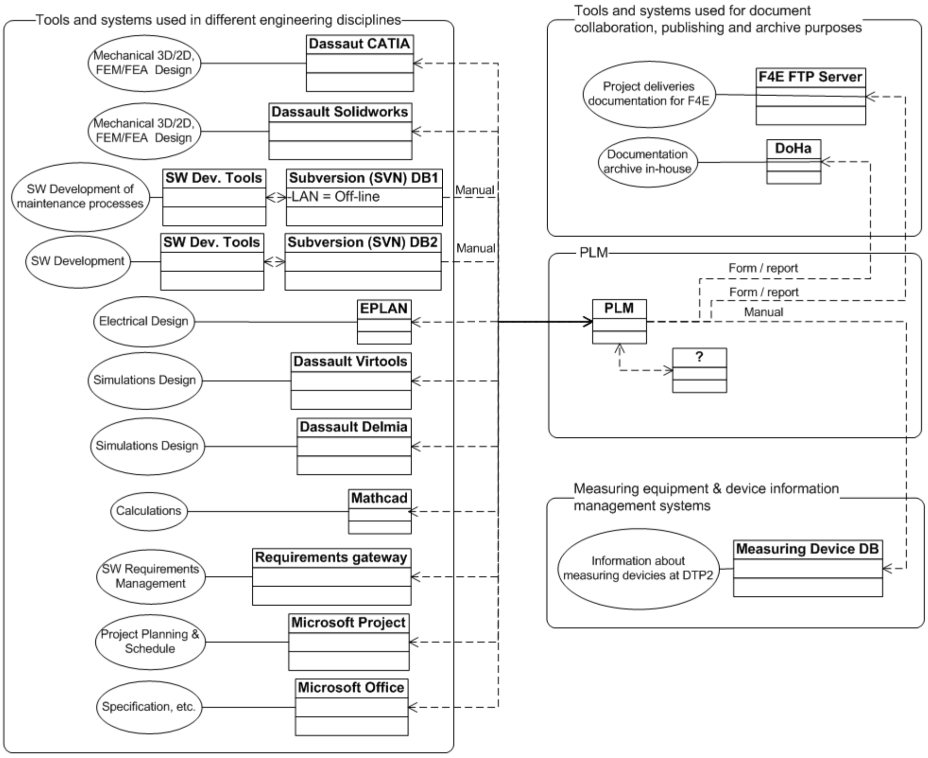
Table 1 Main PLM platform requirements

Requirement	Definition
General PLM requirements	Item management, document management, structure and relationships
	Engineering change process management, change history, product information history management
	Harmonized and centralized product information related to different lifecycle phases
	Harmonized management of product information, easy to access right and up-to-date product information, increased product information quality
DTP2 special requirements	Intelligent collaboration between different DTP2 engineering disciplines and stakeholders; system engineering support, requirements management
	Virtual models management: Virtual prototyping, VR, remote operation, product structures
	Management of the mechatronic product and the individual configuration of DTP2 and its maintenance process.
Mechanical and electrical design requirements	Intelligent management of 3D-CAD models, CAD –document revision and version management, support for E-Plan ECAD
	Support for ITER mechanical design metadata and formats
Software design and control room requirements	Subversion SVN integration support, relations to SRD and other domains. Support for hardware and software configuration management
	SW design authoring tools interface
System testing requirements	Test planning, system test sequences management
	Relations to requirements and SRD documentation
Project management and administration requirements	Project management and project documentation management support, automated and smoothened reporting and deliveries
	Project task breakdown relation to product structure model, project workflows support
	Relationships with F4E and ITER codes and naming policy, workflow

3.2 PLM architecture

PLM Architecture (Figure 3) defines framework needed from information system point-of-view to achieve the proposed roadmap. It is an outcome from interviews and workshops. It consist of system needed to create, update, and dispose product information in different engineering disciplines, main authoring tools and types of IT-systems needed in the PLM area and main information flows needed between the authoring tools and/or systems. On the left hand side the Figure 3 the used authoring tools are presented. On the right side the needed PLM –system functionalities to fulfill the process support, as well as the tools and systems needed for collaboration, publishing and archiving purposes and the system used for managing measurement devices are presented.

Figure 3 DTP2 PLM architecture



3.3 *Mechatronic product data model*

Product data model defines concepts needed to describe the DTP2 system. An item and item structure is used to represent one configuration of the DTP2 or a part of a DTP2 configuration. In the PLM –system there exist a number of DTP2 design configurations needed for different purposes, e.g. conceptual design, new design or simulation design. Those designs have always a relationship to product individuals. The product individual is used to represent physical on-floor configuration of the DTP2. Both item and product individual configurations include up-to-date configuration as well as configuration history. An item i.e. design configuration can fulfill one or more required functionalities and those are defined with the functional breakdown –object. These objects together with the document- and requirement –objects are mainly used to represent the configuration of DTP2 and relevant design information. Some of the object and definitions of required product data model are based on the PLCS –standard [11].

Figure 4 presents one example of DTP2 Mechatronical Product Model. The Mechatronical Product Model includes the structure of DTP2 main system divided to Platform, Divertor Casette, WHMAN Manipulator, Remote Operation and CMM Robot. All these main modules of the DTP2 configuration are classified as Systems and are presented with an item and item structure. Both Main Systems and Systems are used to manage the whole Mechatronical Product Model of DTP2, so in other words they cross-over the boundaries of different engineering disciplines.

Figure 4 Mechatronic product model

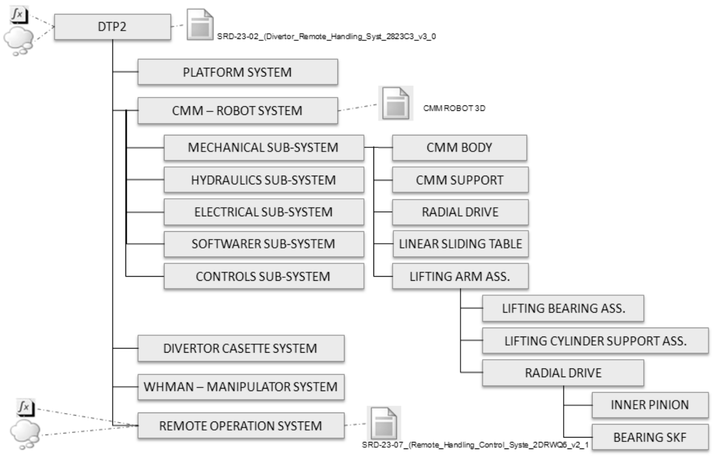
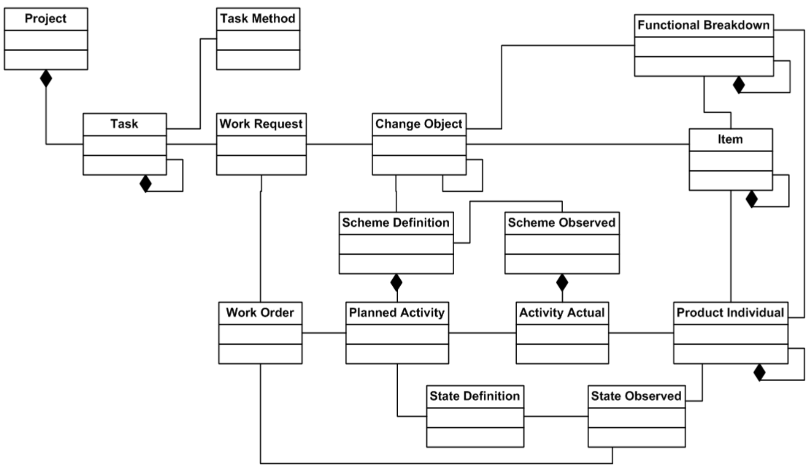


Figure 5 presents the main objects required for the product data model. The item and item structure is used to represent one configuration of DTP2 –system or a part of a DTP2 –system configuration.

Figure 5 Product data model



3.4 Supported PLM processes

In Table 2 are listed the core processes of DTP2 PLM and expected benefits. The processes will be enabled with following main PLM Functions: Document Management, item Management, product individual management, workflows management, engineering change management, product in-use management, project management, reports management, custom forms management, requirements management, systems and/or functions, breakdown management

Table 2 Supported core PLM processes

Core Processes	**Benefits**
Core PLM	
Mechatronic product process: Process to design and maintain the configuration of DTP2 Main System in collaboration with engineering disciplines in question. Product Individual Process: Process to maintain the configuration of DTP2 Main System Product Individual in collaboration with engineering disciplines in question	Increase the visibility and understanding of DTP2 Main System configurations between different stakeholders Manage product data in a cost efficient way, Boost the usage of existing design competencies Reduce costs by providing easy access to up-to-date product information
Smooth and effective PLM process support	
Design Process: Implement a more accurate, effective and automated Design Process Engineering Change process: Implement a more accurate, effective and automated Engineering Change Process Product Individual Maintenance Process: Manage the information and process to store information about maintenance and simulation tasks carried out.	Better quality of product data Product In-use maintenance history Optimized collaboration processes with different stakeholders Shorten development time Cost efficient engineering change management More accurate, effective and automated Engineering Design Process
Project management and delivery support	
Project Management process: Implement processes and tools in PLM –solution to manage project. Publication, reporting and delivery process	Automate the project management process Shorten project delivery and reporting times
System engineering process support	
System Engineering process: Implement processes and tools in PLM –solution to the system engineering process and related information.	Automated and accurate system engineering process Reduced cost by providing easy acess to up-to-date whole product lifecycle information

4 Discussion and Conclusions

This paper introduces results from the DTP2 PLM platform development project. From PLM perspective DTP2 is an environment which requires full product lifecycle support. PLM has to support the unique long in-test and in-use timeline of several decades. Long lifecycle means that even if the used IT –solutions of PLM most likely will change, the product data itself should be accessible for several decades.

PLM platform requirements specification was created collaboratively with the PLM end users during several interviews and workshops. The created PLM platform defines common understanding of PLM framework, roadmap and key development areas, PLM –related requirements, common PLM –processes, common product data model, a PLM system architecture framework, and needs for legacy data harmonization/consolidation. Strategy is to proceed top-down starting from main requirements and step-by-step going to a more detailed view. PLM platform development faces some challenges. Different persons understand PLM definition and terminology in a number of ways. In the PLM framework there are number of different requirements depending on who you ask and it is hard to prioritize those.

One key point of PLM platform development is to support system engineering approach of the multi-disciplinary DTP2 development. System engineering and PLM approaches have lot of similarities. System engineering is strong in multidisciplinary engineering and systematic chain from end-user requirements to functional requirements and finally technical solutions. PLM should support these activities for instance with good requirements and engineering change management capabilities. On the other hand, PLM is strong both in product type and product individual data management. From PLM approach point of view, there are also challenges in implementation, because conventional PLM installations do not support system engineering of a mechatronic system in best possible way [7], [8], [12]. In present implementations, PLM is also usually utilized in detail engineering and design phase, not in the fuzzy concept or research phases. Typical topics for the optimization of the development processes and later realization in PLM solutions are complexity management, integration from requirement management to product structure, multi-domain (mechatronic) functional product description and collaboration [13]. These are essential topics in DTP2 PLM development as well. From PLM research viewpoint, DTP2 is interesting because the product itself and the PLM platform are public, unlike in case of the many companies.

Because of increasing involvement of software development in a mechatronic system, the role of Software Configuration Management (SCM) systems have become important. Due to the lack of functionalities in the PLM systems, they cannot support well the software development process [14]. Anyway, SCM must be united part of the overall PLM architecture. Virtual engineering has been extensively used in DTP2, what poses some challenges. The amount of virtual engineering related data is relatively large and increasing continually. Because DTP2 facility is subject to revisions, updates and upgrades, engineering changes together with virtual models' versions and revision should be managed well. Data and specifications originate from different locations, therefore synchronization and reconciliation of data between parties is essential [3].

The proposal is to continue PLM development, implementation and deployment in steps. Based on the PLM platform and requirements definitions, PLM systems evaluations have been conducted. In the next step the goal is to implement core IT-platform for PLM. This includes the core functionalities to maintain the configuration of DTP2 Main system in collaboration with different engineering disciplines and the management of product individual configuration as well. The aim in steps after that is to expand the platform to design and engineering change related process and workflow support, the product in-use history maintain, project management and delivery support processes, and finally implement more systematic processes to support the systems engineering.

Acknowledgment

We acknowledge all persons who have participated and contributed in the DTP2 PLM platform development.

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Improving efficiency in Product Lifecycle Management implementation projects by applying lean principles

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Abstract: Product Lifecycle Management (PLM) is a business activity which includes a complex network of remotely located stakeholders within and beyond organizational barriers. As such, PLM implementation efforts are far from straightforward business improvement projects and resources and deadlines are usually exceeded. On the other hand, lean initiatives (application of lean principles, methods and tools) have demonstrated being very useful to reduce and control time and costs. In this paper we will consider the possibility to improve efficiency on PLM implementation efforts by applying lean principles. To do this, we will briefly discuss critical areas involved in a PLM implementation as well as lean principles and some of the methods and tools classically labeled "lean". Finally, several OEMs have been surveyed to depict current industry practices in this field.

Keyword : PLM introduction, statistical analysis, pilot project, user needs

1 Introduction

On the one hand, successful PLM implementations are rare (Schuh et al, 2009). Their complexity resembles, in many ways, those early 90's business transformation programmes which many organisations went through to deploy their Enterprise Resource Planning (ERP) solutions. Implementing a PLM solution requires also changes at different levels since "it has effects on business processes, communication policies and control mechanisms" (Silventoinen et al, 2010).

Terzi and Garetti, (2009) pointed that PLM projects include two different categories. This paper particularly refers to the implementation of collaborative environments and platforms. These, also called Collaborative Product Development Management (CPDM) suites, enable a more efficient storing, sharing and management of product data and their adoption involves other departments taking part of the product's lifecycle. From a systems thinking viewpoint, the outcome should result in a "high quality system that meets or exceeds customer requirements, reaches completions within time and cost estimates, working effectively and efficiently in the constantly evolving company's context and infrastructure and has an optimum cost of ownership" (Alemanni and Ciriello, 2010). Company context and legacy systems are clear drivers to select the PLM implementation approach taken. "While more users are thinking of implementing their second, third, or even greater ordinal number of PLM systems, migration is a prominent issue that has to be tackled during the implementation stage. Existing PLM data, processes, and user habits built for years cannot be discarded" (Chen, 2010).

In contrast, lean has its foundations in the world of manufacturing and its principles are more typically applied in the processes and activities that are part of product development. A series of tools and techniques are applied to continuously improve products i.e. to remove waste from these processes. It often requires a mindset change as you are obliged to think about value from a customer perspective. This view is pertinent to service provision as in this context the actors are primarily engaged in the task of managing information and the 'means of productivity' exist in the ability of knowledge workers to understand and to manage the expectations of customers. A PLM implementation is about managing information to provide an optimum service to a customer, and to provide this competitive service it is necessary to understand lean from a knowledge work perspective.

Probably one of the most widely referred to models on the concept of lean was introduced by Womack and Jones (1996) in order to describe the elimination of waste through the application of five lean principles:

1. Specify value from the perspective of the customer,
2. Identify the value stream for a product and eliminate the waste,
3. Enable the smooth flow of work through the value stream,
4. Design and provide what the customer wants when they want it,
5. Continually remove waste to pursue perfection.

It is these principles that we keep in mind in this paper.

2 Research aim, objectives and methodology

This paper aims at answering the two following research questions:

- How could the application of lean principles improve efficiency and effectiveness of PLM implementation projects?
- Which are the views from traditionally mature PLM industries on this subject?

The research objectives are therefore defined as:

- Find a connection between critical areas within PLM implementation initiatives and the application of lean principles to improve performance in information intensive environments.
- Present evidence of the extent of the application of lean within PLM implementations.

An extensive literature review collating PLM and lean literature contribute to achieving the first objective. To reach the second objective, a survey questionnaire was completed by eight representatives that have participated in large PLM implementation projects in their respective OEM organisations. These are operating in the aerospace, defense and automotive sectors. The questionnaire contained ten multiple-choice-answer questions designed based on preliminary discussions on the topic.

3 Literature review

During the last two decades, there has been an evolution in the way manufacturers perceive and understand PLM. Some of them have even designed a top level PLM vision and mission in line with their business objectives. On the second level, best-in-class users

(Aberdeen, 2006) have defined roadmaps, targets and programme management artifacts to realize them. However, although most of the observed PLM efforts are aligned with a broad vision of PLM, there is still need for a full and coherent PLM implementation framework (Schuh et al, 2007).

To manage long-term sustainability in a PLM implementation and maintenance project, a methodological approach is mandatory for achieving planned goals in time and budget. Even if major PLM vendors already have project management best practices for PLM implementations, all these standard approaches unfortunately are often not tailored on complex industrial organisations and their architectures. (Alemanni and Ciriello, 2010). Also, different authors agree that today's challenges of PLM initiatives in companies are those related to diffusion, multi-level integration and adoption (Alemanni and Ciriello, 2010; Centric Software, 2010). More specifically McAfee (2003) stated some deficits in PLM implementation are "incongruent PLM objectives, deficits in project management and the lack of early noticeable outcomes".

If we also consider the extended enterprise stakeholders as fundamental to end-to-end PLM projects, it is worth mentioning that recent surveys reveal that implementation of PLM systems at the supplier side contains additional difficulties (Le Duigou et al, 2010) related to "the match between software functionalities and the user needs**,** the lack of modeling skills and the lack of interoperability between PLM and CAD and ERP".

Literature is also extensively trying to understand the reasons for this complexity. Deficits in project management are a commonly reported reason by which many projects fail. Also the fact that PLM objectives may be clear but they way of achieving them certainly differs from one stakeholder to another along the value chain. This may lead to a PLM solution that offers advantages for one stakeholder but at the same time disadvantages for many others (Schuh et al, 2009). Equally, the confusion between PLM as a broad concept and PLM as mere software application makes difficult its implementation in practice (Schuh et al, 2007).

According to several recent PLM studies (Terzi and Garetti, 2009; Schuh et al, 2009), errors in project planning and change management resistance as well as bad synchronized processes or error in data along the value chain are some of the challenge areas most of the companies feature within their PLM implementation efforts. Particularly, systems deployment is one of the areas to pay attention to since it includes critical tasks such as mapping of current processes to the features of the selected software systems and also identifying customizations and prioritizations (Bachala et al, 2006).

In contrast, not as much is said about the actual measures to minimize the discussed challenges. In general, authors take two complementary approaches to addressing PLM implementation challenges. A first, more conceptual approach in which recommendations are given as a set of guidelines to be applied by the PLM programme stakeholders in a wide variety of contexts (Schuh et al, 2009; Alemanni and Ciriello, 2010); and a second approach which provides more detailed instructions to improve performance in a specific context (Le Duigou et al, 2010; Wren, 2010).

On the "lean thinking" end, May (2005) argues that lean thinking for knowledge work, such as PLM implementation projects, is conceptual and does not require a literal translation. We do not need to directly translate the lean manufacturing methods but focus on gathering and understanding customer requirements, collaboration, relationship building and innovation. May goes on to point out that we need to keep in mind, the need to have a human centered approach and to know that 'information is the primary basis of value' in knowledge work.

Another fundamental thinking change is to characterize waste in the context of information management. Hicks (2007) presented four fundamental causes of waste. They are:

1. Information that cannot flow because it has not been generated,
2. Information is unable to flow because it cannot be identified,
3. Excessive information is generated and maintained, and
4. Inaccurate information flows.

He went on to define four corresponding types of waste:

1. Failure demand, the effort required to overcome the lack of information,
2. Flow demand, the effort required to identify the information that needs to flow,
3. Flow excess, the effort overcome information overload, and ,
4. Flawed flow, the effort to correct inaccurate information.

In his study of product development processes, Bauch (2004) proposed ten different waste types including information and knowledge. The ten waste types include the original seven identified by Ohno (1988) plus three extra ones identified in the study. The additional waste types are:

1. Re-invention or poor re-use of existing knowledge and designs,
2. Lack of system discipline e.g. unclear project goals and projects roles, and
3. Limited IT resources.

Graebsch (2007) identified thirty-five waste drivers in a student development project which studied waste that occurred during information transfer. The top three were the over-dissemination of information or sending information to people who do not need it, deficient information quality that leads to some form of rework and ineffective communication through unstructured or ineffective meetings.

The connection between PLM and Knowledge Management (KM) objectives has also been studied by many authors (Grieves and Tanniru, 2008; Bermell-Garcia and Fan, 2008; Kiritsis, Nguyen and Stark, 2008). A well quoted 'raison d'être' for knowledge management is to provide the right information, to the right person and at the right time. Kennedy et al (2008) follows a similar logic in discussing the objectives of Lean Knowledge Management as getting the "correct knowledge, to the correct people, at the correct time and of the correct quality with minimal waste".

Traditional lean principles can be adapted to knowledge work but a different focus and thinking is required. There is a clear emphasis on what is of value to the customer, how this information flows and how it can be continuously improved.

4 Results and discussion

So how should lean principles be thought of in a PLM implementation context? The keywords to consider are customer, value, information flow and innovation (continuous improvement). These promote a series of questions including; who is the customer, what is valuable to them, how should the information flow to the right people and at the right time and how do you continuously improve?

The connection between Lean Thinking and Knowledge Management is well defined in the literature (May, 2005; Kennedy et al, 2008). What is less well document are examples of the application of Lean Knowledge Management and no examples of using Lean Thinking in the context of developing a PLM implementation could be found.

It is clear that Lean Thinking can be applied in this context but there are challenges for anyone considering it. They include:

- Knowledge elicitation: identify the customer needs through facilitated discussion with the customers. Understand what the basic, performance and excitement needs are (see Figure 1: Kano Model).
- Information structuring: translate the needs into an implementation design.
- Process design: to identify the value adding activities in the PLM implementation.
- Relationship management: the need for successful collaboration between the actors in the implementation requires good relationship management (Abrams et at, 2003).
- Information value measurement: intangible assets (information and relationships) are notoriously difficult to measure. To be able to manage these assets, performance information is needed (Marr, 2008).
- Understanding of lean, knowledge management and quality tools: there are a suite of tools available (e.g. value stream mapping). The challenge is to adapt the available tools to suit the context.
- Understanding of lean, knowledge management and quality tools: there are a suite of tools available (e.g. value stream mapping). The challenge is to adapt the available tools to suit the context.

To try to answer these questions, Table 1 presents authors' recommendations to address PLM implementation challenges found in literature following lean principles. These recommendations are also supported by PLM implementation experts at Airbus CIMPA, a PLM services organization. The purpose of these recommendations is not to provide an ultimate solution to the challenges mentioned, but to express that at least one of the lean principles can be considered to minimize each of the challenges listed. Also different interpretations regarding both the implementation challenges and the lean principles could lead to alternative results, i.e. matching implementation challenges with other lean principles; however this should not conflict with the purpose previously described. In addition, Table 2 shows an extract of the survey results related to the questions above.

Is it possible to apply lean principles in the context of PLM implementations?

. Are PLM implementation challenges related to customer, value, information flow and continuous improvement?

. Could the application of lean principles improve performance of PLM implementations?

Are there any traditionally labelled "lean" methods and tools being used?

. How are organisations currently measuring their PLM implementation efforts?

Some of the lean thinking fundamentals mentioned in Table 1 are described as follows:

- *Customer Value:* The PLM engineer designing and managing the implementation has to elicit customer needs in a way that reflects their expectations. Customers can identify one hundred to four hundred needs (Hauser, 1993), including what they assume a service will provide (basic needs), what they want the product to do (performance needs) and the needs that if provided will surprise or excite (excitement needs). The Kano model (Figure 1) of customer satisfaction defines a competitive product as meeting basic attributes, optimizing performance attributes and including as many excitement attributes as possible. From a lean perspective the customer sets the value and any departure from providing customer value adds to costs. Seddon (2005)

Table 1 Connecting PLM implementation challenges with specific lean principles that could potentially minimize them

Critical areas within PLM implementations	Application of lean principles	Comments
Match between software functionalities and the user needs (Le Duigou et al, 2010)	Define value from the perspective of the user (customer)	Understand what the customer needs and specify value before using lean techniques
Negotiation process between various PLM stakeholders (Schuh et al, 2009)	Define value from the perspective of the user (customer)	Value includes the "intangible aspect of building collaborative and engaging relationships with customers" (May, 2005)
Bad synchronized processes or error in data *(waste)* along the value chain (Schuh et al, 2009)	Make the value creating steps flow	Crete a flow in the value chain so that processes are in line and consequential data errors are minimized
Errors in project planning (Terzi and Garetti, 2009)	Design and provide what the customer wants only when they want it	Provide a project plan that the customer needs
Change management resistance (Terzi and Garetti, 2009)	Pursue perfection	Implement a continuous improvement mindset
Mapping of current processes to the features of the selected software systems *(value stream mapping?)* (Bachala et al, 2006)	Define value from the perspective of the user (customer)	Use value stream mapping (tool not a principle)
Identifying customizations and prioritizations *(identifying customer value?)* (Bachala et al, 2006)	Pursue perfection	Challenge how the product works, expose waste and improve the result
Targeting the right value opportunity *(understanding and defining value)* (Wren, 2010)	Define value from the perspective of the user (customer)	Identify the value opportunity in collaboration with the customer
Process requirement definition within concept design phase of the PLM solution (Gerber, nd)	Define value from the perspective of the user (customer)	Ensure that you specify value at the concept stage before applying lean techniques. No point in providing the wrong 'solution' in an efficient way

defines failure to do something right for the customer in a service organization as "failure demand". The knock on effect of failure demand is a high cost in information rework.

- *Creating Flow:* Hicks (2007), suggests that the value creation steps (value stream) should be designed to enable the efficient movement of information and that the most valuable information flows. The series of activities that deliver the customer needs identified in the previous step need to be mapped. Information should be available as required (information pull) duplication of information should be minimized, out of date information should be minimized and IT interfaces should accommodate these activities.
- *Continuous Improvement (Pursue Perfection):* May (2005) describes this as 'achieving mastery' and includes it as a fundamental goal for lean thinking. By incorporating new knowledge or reusing existing knowledge it is possible to create opportunities to improve. Traditional lean thinking describes this as 'pursue perfection' to strive to remove waste as it is uncovered. In the domain of a PLM implementation this requires collaboration with all actors in order to reuse what it is known and to improve what has to be offered.

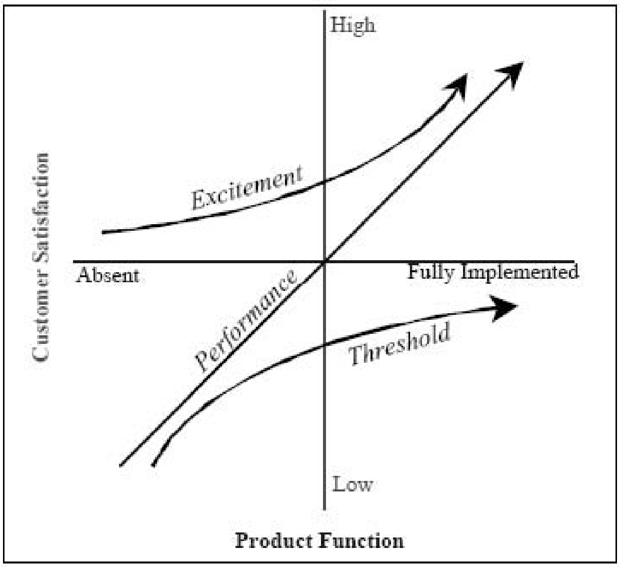

Figure 1: The 'Kano' Model

Table 2 Extract of survey results on applying lean principles within PLM implementations

Current practices and perceptions on applying lean principles within PLM Implementations		Response (%)
Has your company included "lean thinking" principles in their PLM implementation efforts?		
a.	No, we have not taken any "lean" perspective in our implementation activities	50.0
b.	Yes, we have taken "lean" principles to assess the efficiency of our PLM implementations	37.5
c.	I am not sure.	12.5
Are you using "lean" methods and tools to improve efficiency and effectivity of your PLM implementations?		
a.	No, we are not consciously using any "lean" method for this purpose	12.5
b.	Yes, we are using some of the traditional "lean" methods and tools for this purpose	75.0
c.	I am not sure.	12.5
Which of these tools are you using within your PLM implementation activities? (please tick all that apply)		
a.	Statistical Process Control	12.5
b.	Quality Function Deployment (QFD)	25.0
c.	Pull information methods	-
d.	Value Stream Mapping (VSM)	37.5
e.	Supplier involvement in the design of your PLM solution	25.0
f.	Housekeeping (5S)	-
g.	Product and process simplification	37.5
h.	Elimination of buffers	25.0
i.	Failure Mode and Effects Analysis (FMEA)	12.5
j.	Rewards and recognition	-
k.	Other.	50.0
Do you think your company's PLM implementation programme benefits/would benefit from applying "lean"?		
a.	Yes	75.0
b.	No	-
c.	I am not sure.	25.0
How is your company planning to measure the gains achieved through effective PLM? (up to 2 answers allowed)		
a.	Assuming they will facilitate the achievement of overall company targets	50.0
b.	Implementing finance metrics (ROI, monitoring the business case, etc.)	50.0
c.	Implementing PLM system related metrics	37.5
d.	Implementing product development related metrics	25.0
e.	Through stakeholder and user feedback and surveys	25.0
f.	Other.	12.5

Table 2 reports some of the results from a questionnaire survey on PLM implementation practices. These are the answers related to perception and application of lean principles within PLM implementation projects undertaken by industrial participants. The overall survey participation ratio was 67%. The figures shown in the response column correspond to percentages over the total of eight participant organisations which completed the survey.

From these answers, it is apparent that:

a) Half of the companies that participated in the survey admit they have not considered lean principles within their PLM implementation efforts. Therefore, there is an improvement opportunity by assessing objectives, plans and implementation tasks such as deployment strategies with a "lean principles" mindset.

b) Most of the participants report to be already using some of the traditionally labeled "lean" methods and tools. However, some feedback comments indicate that this is done in specific contexts and not consistently applied throughout the implementation. In addition, they perceive a better understanding and application of lean principles within their PLM implementation programme would be beneficial.

c) Some companies still lack of consistent set of performance metrics from their PLM implementation initiatives; and those using them, mostly rely on finance and system related metrics, ignoring other critical ones such as product development metrics.

5 Conclusions

Lean principles can be applied in the context of PLM implementation projects since they are information intensive initiatives which strive for delivering the right information to the right people at the right time. Also, the authors suggest that PLM

The survey reports that currently still most of the companies are using traditionally labeled "lean" methods and tools within operational elements of their PLM implementation projects. However, only half of the companies admit they have considered "lean principles" as a mindset to improve their PLM implementation initiatives. Yet, most of them agree that doing so would benefit the overall performance of such initiatives.

To conclude, more work needs to be done in two streams. Firstly, some feedback from participants indicated that a deeper analysis to contextualize the answers may be needed. Secondly, efforts shall be put towards validating, measuring and enhancing the listed recommendations in the context of PLM implementation projects with industrial case studies.

Acknowledgment

This work would not have been possible without the following individuals: Chris McMahon (University of Bath) for his open support and guidance, Howard Nichols (KTP Programme Office) and Greg Knapton (Airbus CIMPA) for their encouragement and sponsorship. Finally, we would like to express our gratitude to all representatives from the companies involved in this study. Thank you all for your time and support.

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Challenging Requirements Management Issues in PLM Implementation - Findings from a Retrospective Case Study.

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Abstract: In this paper, a recently conducted PDM implementation project in the manufacturing industry is analysed. The aim is to clarify the role and impact of requirements management methods and processes in PLM implementation projects. A literature review summarises existing PLM implementation models. This is followed by an in-depth examination of how a real PDM implementation project was conducted, mapping out the rationale for different courses of actions and the effects they have resulted in. The most challenging requirements management issues in the PDM implementation project are identified and discussed. It is demonstrated that requirements management activities need to form a coherent whole from scoping to testing to contribute to a successful project outcome.

Keywords: PLM implementation, Empirical study, Implementation model, and Requirements management.

1 Introduction

1.1 PDM system implementation – motives and challenges

Product Data Management (PDM) systems must be continuously upgraded over time. Minor changes to PDM processes can usually be realised through different add-ons and customisations to the existing system. However, the gap between the desired processes and the support available from the existing system eventually becomes too large, leading to a need for systems replacement. When using a commercial PDM system for the implementation a gap always exists between the desired processes and the available support from the system. Therefore, two main strategies exist in PDM implementation: customise the commercial system to fit the desired processer, or change the desired processes to fit with existing support in the commercial system (Saaksvouri and Immonen, 2005).

Product Lifecycle Management (PLM) implementation projects are complex. Grönvall (2009) compares PLM implementation with heart transplantation and states that PLM implementations carry many dependencies and uncertainties and therefore are high-risk projects. Several authors (e.g. Saaksvouri and Immonen, ibid) stress the importance of a thorough analysis of business processes and requirements before implementing a

PLM system and while the purely technical part in itself might be a challenge, the organisational part is even harder (Garetti et al, 2005).

The economic benefits of more efficient PLM solutions and PLM implementation are well-known. However, other benefits may be highlighted as well. More efficient PLM solutions may reduce the environmental load occurring in the development process, e.g., in less CO2 emissions from travel to meetings and less material consumed to produce physical prototypes. Moreover, like other major organisational changes, PLM implementation adds to the already existing pressure in organisations. Smoother transitions from current state to future state minimize the extra pressure and thereby contribute to a healthier work environment.

1.2 PLM implementation support

Several theoretical process models for PLM implementation have been proposed (for example, Schuh et al, 2007; Bitzer et al, 2008; Batenburg et al, 2006; Kumar and Midha, 2006). They focus on requirements management support for early phases of a PLM project, resulting in a system being selected, but provide less detailed instructions for subsequent tasks (how to customise the system, for example).

Other authors compare the use of different implementation processes (e.g., Morandotti, 2007; Wognum and Kerssens-van Drongelen, 2005). Eynard et al (2004, 2006; see also Merlo et al, 2005) suggest a specification-driven, object-oriented approach to describe requirements on a PDM system. Wognum and Kerssens-van Drongelen (2005) suggest an evolutionary approach, as the focus in PLM implementations tends to change. The recommendations thus differ; no dominant PLM implementation reference process has yet emerged.

Some works based on empirical case studies have also been presented (examples include Pikosz et al, 1997; Rangan et al, 2005; Wognum and Kerssens-van Drongelen, 2005; Zimmerman, 2008). They formulate guidelines for what to do when implementing PLM, both regarding requirements management and organisation change management. They state what needs to be accomplished, but provide less guidance on how to carry out the task (for example, *how* to minimise customisation). In addition, where cases are referred to, the implementations in such are only briefly described (with the exception of in Zimmerman, 2008). As a result, readers of those articles may find it difficult to apply the guidelines in practice, and to understand what the consequences can be if they are not applied.

We conclude that there is a lack of research that focuses on the operational level of PLM implementation, specifically regarding requirements management and PDM system customisation. Systematic studies of real implementation efforts are essential in order to bring out this knowledge.

1.3 Research aim and approach

The aim of this paper is to clarify the role and impact of requirements management in PLM implementation. Furthermore, the paper aims to identify and discuss challenging PLM implementation issues. This is done through an in-depth study of a recent PDM implementation project in the manufacturing industry.

1.4 Paper outline

The remainder of the paper is structured in the following way. Section 2 first outlines the research approach taken in the study. A thorough description of the project studied is presented in Section 3, followed by a discussion of the most challenging requirements management issues in Section 4. We then discuss the research approach and validity of the results in Section 5. Finally, we present our conclusions in Section 6.

2 Research approach

PLM implementation projects are complex and multi-dimensional. Project organisation, process, methods, and changes in the global economy are only some of the aspects that affect project outcome. Therefore, a qualitative systems approach has been used in the research. This calls for an in-depth case study (Yin, 2003), with multiple data sources such as interviews, documents, reference group meetings with company employees and seminars, in order to understand the underlying factors for courses of actions and to minimise bias.

The project studied was conducted during 2006-2009 at a multi-national company in the manufacturing industry (hereafter called GlobalGroup). GlobalGroup delivers commercial solutions in various areas and is divided into multiple divisions, some of which were involved with the studied project.

GlobalGroup used (and still use) several PDM systems with different functionality. Some are developed in-house while others are based on commercial off-the-shelf (COTS) systems from different vendors. Earlier, they had gone through a larger PLM initiative (cf. Zimmerman, 2008) that resulted in a decision to phase a PDM system from one of their vendors (hereafter called VendorCorp). GlobalGroup decreased the maintenance budget for the system, but it continued to work well and was not shut down. However, in the summer of 2006, VendorCorp announced that their system support would end in two years' time. Unwilling to take the risk of using a system not supported by the vendor, GlobalGroup decided to replace it, together with some other systems connected to it.

The case is a suitable object for study for three main reasons. First, the project has been performed in a multi-national environment in a company with multiple sites and company divisions around the world. Also, the two systems (before and after) were significantly different. The architecture and user interfaces of the systems differ, and the new system enables a much more comprehensive PLM support. The case therefore allows for insights into a wide range of PLM implementation issues. Second, the company studied has performed several PLM implementation projects prior to the actual case. Therefore, it represents current practice within the field, without having to regard "beginner" issues. Third, the project recently ended, during the fall of 2009. Therefore, the findings reflect current PLM practice.

Seventeen semi-structured interviews (with 21 interviewees) were performed during the case study. The interviewees were sampled according to a heterogeneous strategy in order to represent as many viewpoints as possible. All interviews lasted for two hours each and were done by at least two interviewers, and were recorded, transcribed and sent to the interviewees for validation.

In addition, more than 200 project and company documents were analysed. Examples of those documents include white books, meeting minutes, communication letters and technical documentation.

As part of the data structuring, interview statements were cut out and grouped into five main areas, as presented in Section 4. Communication letters and meeting protocols were summarised in a few sentences and added to the analysis, and the technical project documentation was analysed in depth.

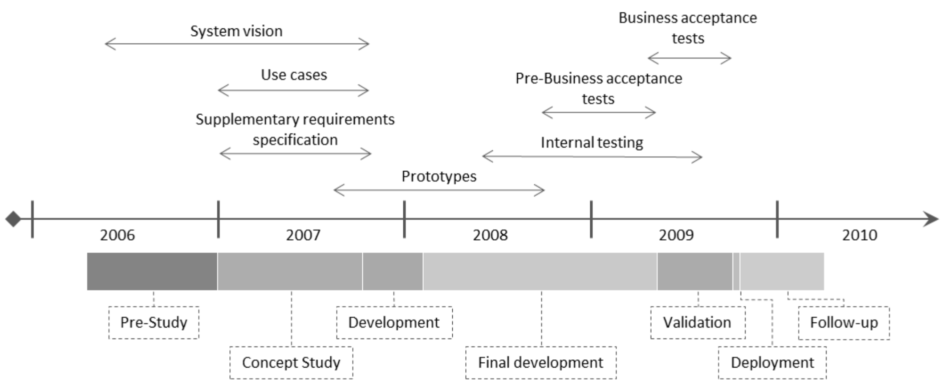
For validation, preliminary findings have on three occasions throughout the study been presented for a reference group, which consisted of managers from the IT department and other departments. A presentation with final findings was held for the reference group and most of the participating interviewees. In addition, two presentations were held at another company, with characteristics similar to GlobalGroup. All of these groups corroborated the validity of the findings.

3 Project description

3.1 Implementation process

The project followed GlobalGroup's global project model for the development of information systems. It is a waterfall stage-gate model with seven phases (pre-study, concept study, development, final development, validation, deployment and follow-up) (See Figure 1). In this section, a chain of events through the different phases is presented.

Figure 1 GlobalGroup's project model for the development of information systems, with requirements engineering activities highlighted



3.1.1 Pre-Study phase [October 2006 – January 2007]

A pre-study team, led by the business divisions with input from the ITDivision, concluded that the most suitable solution would be to replace the existing system with a new COTS system from VendorCorp, despite GlobalGroup's strategy to phase out the use of VendorCorp's CAD and PDM systems. To minimise time and cost, processes were to remain the same. The project aimed at a "1:1 replacement" of the existing PDM system with a particular release of VendorCorp's new generation PDM system. The ratio 1:1 meant that all current *processes* should be supported by the new system. However, many stakeholders interpreted 1:1 as having the exact same *functionality* in the new system as in the existing one. GlobalGroup planned to launch the new system during the fall of

2008, and VendorCorp agreed to prolong the support of the existing system until the new one had been launched.

The project had difficulties getting commitment from all necessary divisions. However, it was ultimately given the go-ahead, and a project organisation was set up.

3.1.2 Concept study phase [January 2007 – November 2007]

In beginning of the concept study phase, it became evident that preliminary cost estimations were too low. Several estimations had previously been too optimistic, and a budget for some necessary areas was missing. New calculations performed by the ITDivision pointed to twice the first estimated amount.

The ITDivision elicited requirements and validated those with the business reference group. System vision, use cases (functional requirements) and supplementary requirements specification (non-functional requirements) were constructed. However, the business reference group had difficulties agreeing on the requirements. All divisions used the existing system in different ways, and it was unclear what functionality could be customised in the new system for each division and what functionality had to be common. In order to understand the system possibilities and constraints, the business reference group members took a training course in the new PDM system, the off-the-shelf version.

A project audit, led by GlobalGroup representatives, concluded that the various business divisions had to unite their visions and agree upon requirements. It was also suggested that concept prototypes should be constructed in order to identify critical areas where the COTS solution would not be enough.

The ITDivision constructed the concept prototypes (essentially solution mock-ups in presentation slide format) and presented them to the business reference group. Based upon the concept prototypes, it became evident that the out-of-the-box release initially aimed at would require major customisations to meet the GlobalGroup's needs. The project sent a system change request with additional functionality to VendorCorp, who agreed to include the new functionality in their next release. The project decided to implement the new release instead of the existing one and the consequence was a time delay.

A new large PLM strategy initiative had started and was now running in parallel with the implementation project. VendorCorp was once more evaluated and compared with its competitors by GlobalGroup. This evaluation further delayed the implementation project. However, in late 2007, it was concluded that VendorCorp was one of the two remaining competitors going through a final evaluation. Commitment from business reference group members in the implementation project increased substantially. Shortly after the notice, the project continued to the next phase, bringing with it almost finished use cases, supplementary requirements specifications and concept prototypes.

3.1.3 Development phase [November 2007 – January 2008]

However, work had continued while waiting for the result from the new PLM strategy initiative. Therefore, the development phase was short, lasting from November 2007 to January 2008. Use cases, the supplementary requirements specifications and concept prototypes were finished and approved. It was now assessed that the largest project risk would be a delay in the new product release from VendorCorp, who had promised to deliver the new system release in July 2008.

3.1.4 Final development phase [January 2008 – May 2009]

At the beginning of the final development phase, VendorCorp announced that the targeted system release would be delayed. It was not delivered until November 2008 and the quality of the release was assessed as being insufficient for roll out. So the project had to wait for a maintenance release delivered in February 2009.

During 2008, the IT project continued to customise the system at the same pace. The idea was to develop towards the available system environment and upgrade to the new release later. However, this strategy failed, as several previously performed activities had to be done again when the GlobalGroup received the new release. This led to increased costs. At the end of June 2008, about two thirds of the yearly budget had been spent and delivery was behind schedule. The IT project manager was replaced, and the project was re-organised and re-planned.

The IT project tested the solution in two ways, by internal testing and by business acceptance tests. Test scenarios were based (but modified) on the concept prototypes. Several runs of tests were performed from the fall of 2008 to the spring of 2009 that revealed important issues with the solutions, both regarding functionality and performance. New requirements were identified, some changed and some could not be agreed upon. Performance was slower than what was expected by the users, especially for large assemblies. The date for system deployment was postponed several times, mostly because the project had difficulties progressing. In addition, a business division announced that deployment for them would not be possible at a particular time, due to heavy product releases for one of their departments. The steering committee requested that the business reference group accept workarounds and changes that the IT project suggested, so that the project could move on. Finally, the system deployment date was set for August 2009.

3.1.5 Validation, Deployment, Follow-up phases [May 2009 – April 2010]

The validation phase started in May 2009. The final business acceptance tests were performed, and, after the summer vacation, users were scheduled for system education. After a final migration rehearsal, the project progressed to the deployment phase and replaced the systems in September 2009, about a year later than initially planned. There were some technical problems, but none of critical character. A so-called super-support team was established, aimed at supporting the users with knowledge of how and why tasks needed to be performed in a certain way in order to work. The deployment phase ended in October 2009, and the responsibility for the system was transferred to the maintenance department. In the follow-up phase, learning lessons documents were compiled by the business project, the IT project and the system vendor.

3.2 Project results

In summarizing the project, some gains can be identified. While replacing the old system, several other systems became unnecessary and were removed as well. This has led to a less complex system architecture with a decreased number of systems. Also, divisions and even departments therein used the existing system in their own ways, with different methodologies. GlobalGroup now has a globally standardised way of working, e.g. with release management, that has been enabled (and enforced) by the new PDM system.

However, the initial budget was overrun by a factor of three. A too optimistic initial budget assessment is part of the explanation. But a string of events caused additional delays and thus cost overruns: aiming for the wrong system release, poor quality of the initial version of the target release, delays in internal development, and delays due the fact that that product release was prioritised.

Regarding quality, benefits were gained on the divisional collaboration level through more efficient information sharing. However, end-users indicated a decrease in individual user efficiency. One example of this was functionality that required more and non-intuitive mouse-clicks. In addition, the project consciously disabled a specific system functionality, which led to decreased user efficiency. User satisfaction also varied between geographical sites. In addition, poor organisational change management, e.g. communication about the change, lack of education and user support when the system was replaced, probably reinforced the perception of a decrease in user efficiency in the new system.

Overall, several of the interviewees categorised the PLM implementation project as neither a success nor a failure. It was perceived as a normal outcome at GlobalGroup. They managed to replace their PDM system, but the project was both unnecessarily long and costly.

4 Challenging requirements management issues in PLM implementation

Let us now discuss in more detail some identified challenging requirements management issues in PLM implementation projects, namely project scope and goals, implementation processes, requirements elicitation and validation, system testing and user involvement.

4.1 Project scope and goals

Using a system not supported by the vendor would have been a huge business risk. Therefore, GlobalGroup initiated a project to replace its existing system. Hence, the main project objective can be said to have been minimizing risk. Other objectives were to perform the replacement rather quickly and minimise the cost of the implementation.

The project had difficulties in the beginning to get commitment from all necessary divisions, due to GlobalGroup's earlier strategy of phasing out systems from VendorCorp. Even though the project received a budget and was started, it soon became evident that initial preliminary cost estimations had been too optimistic and some necessary areas were even missing. It was not until the results from GlobalGroup's new PLM initiative was announced that commitment increased, almost a year into the project.

The resulting strategy was to perform a "1:1 replacement", meaning that the new system should provide the same support as the existing one, no less and no more. The aim was to use the existing functionality in the new system, with minimised customisations, an out-of-the-box solution. However, a basic problem with the 1:1 replacement and out-of-the-box strategies was that they were contradictory.

PLM implementation requires knowledge of the business processes (e.g., Saaksvouri and Immonen, 2005). Since the project would be a 1:1 replacement, the business divisions thought there was no need for them to get involved in the project. They argued that the ITDivision already knew how the old system was being used. However, due to the earlier strategy to phase out systems from VendorCorp, maintenance of the existing system had been decreased over a period of several years, and this had resulted in insufficient documentation of the existing system. Therefore, documentation of how the existing system and the process worked had to be created as a part of the project. This led to additional project costs that were not previously anticipated.

Another reason why it was difficult to get business commitment for the project was that the 1:1 replacement strategy was perceived as not providing any benefits. Some interviewees said there were business benefits on a global collaboration layer, but that there were no benefits for an individual user. It was also unclear what a 1:1 replacement meant. Some interviewees interpreted it as the same process support, but with different methods. Others interpreted it as the same functionality and user interface.

Once involved, all divisions aimed to solve their own needs. They were also either unwilling to adapt to, or unaware of how their needs contradicted with, the other divisions' needs. The requirements became harmonised after the project audit, performed during the concept study phase, had highlighted the issue.

In summary, the project scope and goals caused several problems. However, as one interviewee stated it, without the 1:1 replacement strategy that expressed intent to minimise scope and costs, the project might not have received funding at all.

4.2 Implementation process

GlobalGroup's project model (a waterfall stage-gate model) is rather comprehensive, and common views among interviewees were that they "went by the book". Despite this, there were multiple time delays, caused by aiming for the wrong system release, poor quality of the initial version of the target release, delays in internal development, and delays due to the fact that that product release was prioritised. Although a project model should support the assessment and mitigation of external factors, it was unclear how it would deal with these. It seems that would require skills beyond general project management skills and models.

The choice of project model is not self-evident for a PLM implementation project. A waterfall model requires that the complete project scope be completed before the whole project moves to the next phase. Specifying the complete development gap might take a long time. When the specification is complete and the project can move to the next phase, it might already have changed. It is not certain that a complete set of requirements can be described before developing the solution. Wognum and Kerssens-van Drongelen (2005) suggest that a "learning, evolutionary or cyclic approach" should be used for PLM implementation, as the focus in these kinds of projects tends to change. With an evolutionary approach (Sommerville, 2007) the system is more likely to meet the stakeholders' needs and the requirements specification is allowed to develop continuously throughout the project. However, an evolutionary approach is less visible to management, and the system structure is more likely going to be difficult to maintain. Sommerville (ibid) also states that a waterfall process should only be used when requirements are well-understood and unlikely to change often. However, a waterfall process is rather inflexible regarding phases and commitment is needed early, making it difficult to change the scope. Neither of these basic approaches therefore seems to fit fully with the characteristics of PLM implementation projects, which are essentially COTS projects.

Regardless of how the project models look, they prescribe only what should be accomplished at each stage of the project. They do not prescribe how it should be accomplished. On its own initiative, the IT project applied methodology from the iterative work model Scrum. However, this was a first attempt, and integration with the higher-level project model was lacking.

In summary, there was no consensus in the project as to what the best implementation process approach was. Different viewpoints on the implementation process were stated by business and IT, as well as between managements' project models and operative work models. Although different models support the project on different levels, they also affect to what degree collaboration can be achieved between the project actors. An effective PLM implementation process model needs to be two-levelled: a project control level and a work (coding) level.

4.3 Requirements elicitation & validation

When specifying requirements for a COTS system, existing processes and systems must be reviewed and changes to the desired processes and systems must be agreed on. Also, the new COTS system must be reviewed with regard to its possibilities and constraints. The difference between the desired new processes and system and the possibilities and constraints with the new COTS system can be called the "development gap".

No requirements specification templates for COTS implementation pre-existed in the company. Instead, the requirements specification was based on company templates for use cases and supplementary requirements specifications developed for new systems development. The project had difficulties specifying the necessary requirements on the new system. Perrone (2004) states that requirements engineering methods used for the development of systems built from scratch do not suit development using COTS systems. The requirements on COTS systems need to take into account the possibilities and constraints in the system.

A review of the requirements specification documents revealed weaknesses. There were comparably few requirements, and they were written on a high level. The requirements were based on the characteristics of the existing system, and did not align with the possibilities and constraints in the new COTS system. Some of the requirements were contradictory and requirements for specific technical areas were missing.

Further, requirements are dynamic and change, due to both internal and external reasons. Requirement changes will drive other changes. In the project, it became evident from the concept prototypes that the out-of-the-box release initially aimed at would require major customisations to meet GlobalGroup's needs. The project sent a system change request with additional functionality needed in the system, which VendorCorp agreed to include in their next system release. While waiting for the new release, the project continued at the same pace instead of slowing down, hoping to develop towards the available system release and upgrade to the new release when available. Rather, the project should have scaled down during the waiting period in order to follow the requirements dynamic.

All these issues made the requirements specifications difficult to use in reality. In fact, the requirements specification documents ceased to be used when entering the final development phase. The project then shifted to a test-driven mode, meaning that it was driven more by the response from system tests than from pre-defined requirements (cf. Morandotti, 2007).

4.4 System testing

New test case scenarios were constructed for the system testing. These were based on the use cases specified in the beginning of the project, but also included additional and altered functionality that appeared late in the project.

When using a test-driven approach, feedback from business representatives on early prototypes is necessary in order to guide further development. The system developers used several prototypes and business acceptance tests to evaluate their results with business reference group members and end users. But IT found it difficult to get relevant feedback in early phases. An explanation can be found in the degree of readiness at different stages of development. It is known that many people find it easier to have something tangible in front of them when testing a product, whether a physical product or an information system. Wiegers (2003) refers to this as IKIWISI – "I'll know it when I see it". Prototype evaluations were performed on presentation slides to the user community, while the business acceptance tests evaluated the complete solution in the real environment. Naturally, it is easier to give feedback on an almost complete system than on partial concepts on presentation slides. The testers needed to get used to the system first in order to give feedback. Although it was too late at this point to make major changes the early prototypes filled a purpose in announcing that there was going to be a change.

To facilitate feedback on early prototypes, focus needs to be put on communication between developers and the business reference group. However, the business reference group struggled with its own issues.

4.5 User involvement – the business reference group

The main forum for user involvement in the project was the business reference group.

Most of the communication between the IT project and the business divisions took place at the business reference group meetings. The group was led by the chief project manager, who also presented the group's views to the steering committee. At the reference group meetings, the IT project presented how far it had proceeded since last time and indicated what decision it needed by the business reference group.

Most of the business reference group members were from the headquarter site. They represented their own views, rather than those of the global organisation. Lack of time and compensation can be seen as an explanation for this issue, since business reference group activity was something done in addition to regular work. This was a known problem. Previous system implementation projects at GlobalGroup had tried to buy business reference group hours from business divisions in order to secure commitment. Unfortunately, the result had often been that business divisions hired consultants to do the work instead, with insufficient knowledge about processes or methods and with no contact network inside the organisation.

The business reference group members had too little knowledge of the possibilities and the constraints of the new system, making it difficult for them to describe the development gap. Instead, the IT project constructed most of the requirements and validated them with the business reference group to ensure that the processes had been correctly understood. Business reference group members were educated in the new COTS system, but the training was too short for its purpose. Several members were replaced during the project, and some new members were invited to join. Those who joined at a later stage did not receive the new COTS system training.

Unfortunately, GlobalGroup's project model for the development of information systems provided almost no guidance for how to set up, act in, or manage a business reference group. This made the project dependent upon the individuals' abilities in that area.

5 Discussion of research approach and usability of results

In this paper, qualitative findings from a multi-dimensional context are presented. The paper contributes with empirical experiences from a PDM implementation case, based on interviews, as well as project and company documents. Our findings have been presented for our business reference group at GlobalGroup and for interviewees that participated in the study. These presentations are part of the paper's validity construction (cf. Yin, 2003).

Transferability is an important evaluation criterion in single case studies (Guba and Lincoln, 1989). In this case, that means that the findings put forward can be transferred to the reader of the paper. Our intention has been to facilitate transferability by presenting a thorough description of the project, with rationale for courses of action, prior to the description and discussion of challenging PLM implementation aspects.

According to Svensson et al (2002), the generalisation of findings in qualitative, single case studies is possible through the recognition of the results. The findings have been presented for another company with characteristics similar to GlobalGroup's and the attendees did recognise and acknowledge most of the presented PLM implementation issues.

6 Conclusions & future work

This paper has presented an in-depth comprehensive description of how a PDM implementation project has been conducted. The paper discusses the rationale for different courses of actions and the effects those courses have had.

Challenging requirements management issues in this case included the following: the project scope and goals, the implementation process model, the requirements elicitation and validation, the system testing and the user involvement. Methods used to manage these tasks included a corporate project model, use cases, textual requirements, prototypes, various tests, and a reference group. However, they lacked a support for defining an overall scope and business case, for stating customisation rather than green-field requirements, for connecting use cases and tests and for making effective use of the reference group. Consequently, the project drifted from a pro-active, requirements-driven mode to a reactive, test-driven mode. A more skilled application of the requirements management toolbox could have resulted in a more successful project outcome, regarding time, cost and quality.

However, the project also demonstrates the importance of events beyond the project's control. A project scope and strategy with inherent contradictions, a delay of the target release from the vendor, and the need to adapt the launch to the group's product release schedule also caused significant delays and cost overruns. Well-performed requirements management activities are essential, but do not suffice, for a successful project outcome.

Findings from the paper can be used to validate published models for PLM implementation as well as in constructing new ones. Nevertheless, more empirical studies are needed, especially aspects concerning organisational change management, and the adaptation of COTS implementation models to the PLM context.

Acknowledgment

This work has been carried out within the Sustainable Production Initiative and the Production Area of Advance at Chalmers University of Technology in Gothenburg, Sweden. The support is gratefully acknowledged. The authors would also like to express their highest gratitude to all who have participated in the study as interviewees, references or both.

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PLM Adoption Through Statistical Analysis

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Abstract: This paper gives an insight in how statistical tools for customer satisfaction and market segmentation can be used to improve the introduction and adoption process of PLM tools and systems. The suggested method identifies PLM user needs that are important for the PLM introduction strategy, and their effect on the organization. The method further makes it possible to select the most suitable pilot group in order to assure a success story for the future roll out of the PLM system.

Keyword : PLM introduction, statistical analysis, pilot project, user needs

1 Introduction

Since PLM systems are very large and complex organizational systems, planning for change in these systems is essential. It is not just about introducing new systems and thus adding to the pallet of IT systems used within a company; it is also about planning for the future, allowing the technology to be integrated and to plan for continuous improvements.

A company's ability to integrate and incorporate new IT systems, processes etc., is known as the adoption process. Getting the PLM user involved early in the PLM project is important in order to assure adoption of the new PLM system and tools. It is however not the adoption of a new technology in itself that makes a strong strategy; it is rather the mindset of adaptability that is essential [1], hence one important part of this statement is that it is important to adapt the PLM introduction to fit the intended PLM users.

PLM system introductions are a relatively new research area and the research targeting PLM introductions specifically is sparse, however Garetti and Terzi [2] point out that organizational change management theories are relevant and applicable to PLM systems introduction. They further suggest that there are two main ways to introduce a PLM system in an organization: either an overall step-by-step procedure, or by niche and follow-up projects. When considering a niche project and follow-up approach (which is similar to a bottom-up approach), a quick implementation among highly motivated people is done; however, validity of the niche project as a trustable pilot scalable to the whole company is a problem. The step by- step approach (similar to a top down approach) seems to be more reliable regarding collection of user requirements, but requires a lot of time for analyzing the company needs. If these both alternatives could be combined you would be able to secure both the PLM user and the organizational needs in parallel.

The cookbook-related introduction processes used in IT introduction projects might not be applicable to large scale introductions as the introduction of a company-wide PLM system; this has also been shown by Zimmerman et al. [3].

Although the user is said to be the focus of most introductions, it is important to gain further knowledge about engineers' attitudes towards the use of information management systems in product development. There are studies that focus on the user perspective (e.g. [4]) but there remain issues regarding information exchange and collaboration in product development and the difficulties with tool and system integration.

This paper aims to present a method originating in customer satisfaction assessments for the service industry and apply it to PLM users in a product developing organization. This is seen, as a means to combine the top down organizational needs with the bottom up PLM user needs. The method will be used to evaluate PLM users regarding satisfaction of the PLM systems, tools and processes, and how to facilitate a structured roll out of new PLM systems and tools. The research question for this research work is:

How can statistical tools be used to facilitate new PLM introductions?

The question aims to investigate how statistical methods can be used to bridge the gap between organizational needs and business needs to maximize organizational adoption as quickly as possible.

2 Method

The aim of this paper is to present a complete and comprehensive method for how statistical tools can be used to identify needs and facilitate a PLM introduction. In doing so this paper will refer to results from previous case studies published in [5], and [6].

The questionnaire used in the study was previously published in a working paper [7] along with a preliminary statistical model that provided the foundation for the formulation of questions.

The selected statistical methods are used in a complimentary fashion. Cluster Analysis is often presented in management literature as means to identify external market clusters to perform a market segmentation [8, 9]. Partial Least Squares (PLS) is a causal modeling approach which makes it possible to estimate impacts from a multitude of sources. It is growing in use in management and marketing studies [10], for example when evaluating American customer satisfaction index [11]. PLS is a more complex statistical method than e.g. factor analysis that is used in [9] together with cluster analysis.

The statistical methods have been tested at two Swedish independent automotive firms, one manufacturer of passenger cars and one heavy vehicle manufacturer. The surveys were performed in 2007 and 2008 and involved 300+ respondents at each site.

3 Objective

There are many objectives to perform a statistical analysis prior to introduce a PLM system or tool. The objectives can be organized in a few categories regarding their use and impact. The main objectives are presented in Table 1.

Table 1 Objective

Objective	Motivation
Inform PLM users	The questionnaire can contain information and explanations that you want to convey to the PLM users. The survey will also create a state of urgency that can be used to:
Motivate PLM users	The questionnaire can implicitly suggest how information management can be improved. The introduction to the questionnaire can also be used to motivate the PLM introduction. Further the analysis will identify the needs of the users, which is also good for motivation purposes.
Involve PLM users	The PLM user gets involved from the beginning, and gets the chance to influence the forthcoming introduction at the earliest possible stage. Open questions in the questionnaire can also capture issues that the standard questionnaire, and small interview studies does not capture.
Identify improvement areas	The statistical analysis will point out areas that are more important than other areas according to the PLM users. This knowledge is good to have in order to prioritize tasks and when motivating the PLM user. E.g. If Usability is found to be the most important area to the PLM users this can be used in the internal marketing of the new PLM tool.
Group PLM users according to needs	The groups with the highest needs and greatest motivation towards change can be introduced to the new PLM tool first. PLM users who are rather happy with their current tool support can wait until the system runs smoothly throughout the organization.
Identify suitable group for pilot study	A concrete task is to select a group of users that are suitable for being a part of the pilot roll out. If you can choose the most suitable persons you will increase your chance of success.

4 The Statistical Analysis Method

The over all process is based on a standard process [8] of how to work with statistical tools. This process contains six steps and is depicted in Figure 1. The process involves preparation and adaptation of the standard questionnaire. This is followed by the data collection process, where PLM users from the organizations get to answer the questionnaire. After this, three steps concerning the analysis of the data is followed, Missing Value Analysis (MVA) to assure the correctness of the information, a statistical analysis where different software and tools are used to calculate improvement areas and to group users according to their receptiveness to change. The qualitative analysis is done in order to explain the result from the previous steps and to put the results in the relevant context regarding the introduction process. This validates the study. Finally the results are finalized and reported back to the organization.

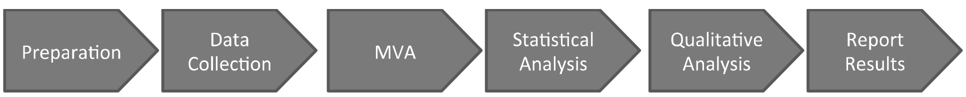

Figure 1 Process for statistical analysis

4.1 Step 1: Preparation

The most important task in the preparation step is to anchor the study purpose in the organization, secure management involvement on all layers, and to inform employees about the forthcoming study. Management is responsible for the correct execution of these tasks. From the facilitator's point of view, the preparation step consists of planning tasks that help to speed up the data collection process and analysis. Tasks that are included in this preparation work also include adjustment of the questionnaire to fit the specific company e.g. by introducing specific categorization questions such as which project the PLM user normally works in.

It is also important to arrange meetings to prepare the management and the employees for the questionnaire, and to give incentives (the objectives) for them to actually take the time to fill out the questionnaire. These meetings will typically give information on how the data will be used, what type of analysis that will be performed, and how taking the questionnaire will benefit the organization and the individual, e.g. through the possibility to customize the introduction process.

4.2 Step 2: Data Collection

In the data collection phase, the questionnaire is launched to the respondents using their unique e-mail addresses. The company needs to allocate time for filling out the questionnaire, and stress the importance for each respondent to assign 20 minutes to answer. Reminders, sent out by the researchers, are necessary in order to get as many answers as possible.

From the case studies a response rate around 60% was achieved after sending out 3 reminders. Using better and more direct communication from the manager closest to the PLM user could probably increase this figure. One example of this that was employed in the second case study was to inform the lowest level managers in person, and then let them inform the PLM users directly on their weekly meetings.

4.3 Step 3: Missing Value Analysis (MVA)

This step and the next include study performer tasks only. Several analysis methods could be performed in order to confirm the data. Traditional missing-data analysis [8] has to be performed to eliminate and identify errors within the data set. Potential errors could originate in that respondents have misunderstood a large range of questions, or simply clicked through the questionnaire without answering the questions. It is also important to identify questions with a high standard deviation and multiple "N/A" answers in order to update or eliminate them in future studies.

Concerning the Identification of improvement areas it is difficult to further assure the correctness of the data provided. It is important to get a high number of respondents, but apart from this the statistical error is difficult to estimate.

Regarding the grouping of PLM users an efficient method to test the data relevance is to perform a factor analysis with each question allocated to one out of three factors named: Satisfaction, Expectation, and Benefits [6]. If the factor analysis matches the qualitative assumption, then the reliability of the data is likely to be high.

4.4 Step 4: Statistical Analysis

This chapter concerns the statistical analysis performed on the corrected data material. From a PLM introduction perspective several different analysis and groupings can be made. The first one is the identification of improvement areas (Scores), the second is the calculation of the impacts of the improvement areas on potential effects (Impacts).

Finally two types of cluster analysis can be made in order to group the PLM users regarding their receptiveness to change and suitability to be part of a PLM pilot group.

4.4.1 Identification of improvement areas

The analysis method for identifying improvement areas are often used in customer satisfaction studies, in order to improve the effect of customer satisfaction and customer loyalty. The main analysis method is called Partial Least Squares analysis (PLS) and involves multiple regression analysis in order to both calculate an index value to each potential improvement area, as well as to estimate the impact of each improvement areas towards desired effects.

The index scores of each improvement area are rated from 1-100 where a high score is better. From this analysis a selection of good areas (that do not need to be improved) and a set of improvement areas are identified. It is important to remember that the scores are calculated regarding the PLM users perception on the different areas. If an area is scoring high it is perceived as high. This could mean that the organization needs to be informed about the difficulties and that more effort needs to be put on motivating the PLM users why a change is needed. However, an area that scores low, does not need the same type of information, here the organization is well aware of the problems. The index scores are illustrated using traffic light color-coding in Figure 2 where red is low score and green is a high score.

Table 2 shows the PLM areas as well as the potential benefits that were used in the case studies. These areas are further discussed in [5].

Table 2 Areas and benefits

Areas	Main Criteria	Potential Benefits
Expectations on PLM	PLM User Satisfaction	Information Quality
Support (IT support)		Innovation
Information Structure		Efficiency
Introduction & Training		Multidisciplinary Support
Usability of tools and systems		
PLM usage (benefits)		

4.4.2 Identification of impacts

Impacts are calculated at the same time as the improvement areas. The impacts are rated in percent on how much the improvement area affects a potential benefit. An area that scores relatively low and which has a high impact on potential benefits is ideal to focus the PLM introduction project on.

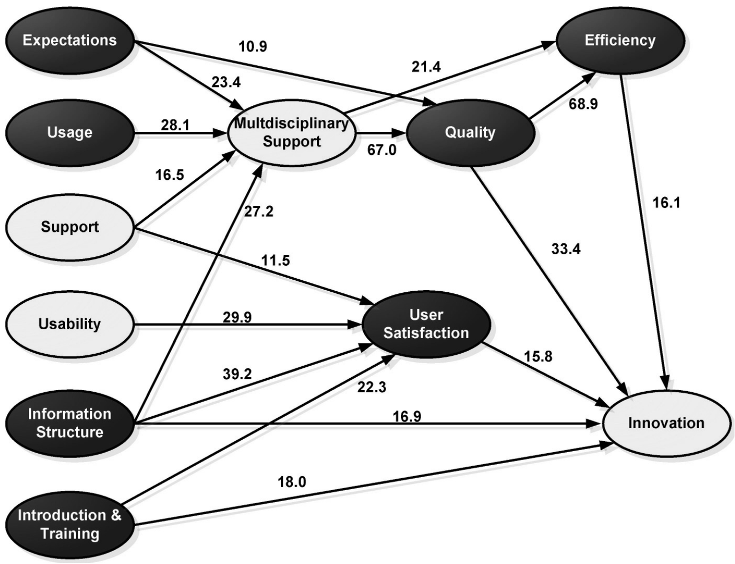

Figure 2 Examples of impacts (in percent). Traffic light color-coding represents the index scores.

From the case studies it was shown that "Information Structure" was an area that had a low score and that in turn had a high impact on "User Satisfaction". This example shows that a focus on better information structure in the PLM project would result in more satisfied PLM users. "Information Structure" also showed high impacts on the "multi disciplinary support" area that in turn affected "Information quality" and "Efficiency".

4.4.3 Grouping of PLM users with similar needs

Cluster analysis is a statistical analysis method that is used in a wide variety of scientific fields. Within economics and market research, cluster analysis can partition the general population of consumers into market segments that are targeted individually. In general, cluster analysis is a set of analysis tools used to classify objects according to relationships between those objects [8]. It is within this context that cluster analysis is used to identify groups of users with similar motivation level that are to be introduced to new PLM system.

The PLM users are grouped regarding three main areas that related to their receptiveness of change. These three areas are Satisfaction, Expectations and Benefits. The two first areas are represented in Table 2 whereas the Benefits are a combination of all the "Potential Benefits" stated in Table 2.

The hypothesis of the grouping is that the satisfaction level shows weather or not you are happy with the current PLM situation. If you are satisfied you are less willing to change. The second parameter, Expectations, show if you have great or low expectations on new PLM solution. The hypothesis here is that if you have high expectations then you are more willing to try and adopt new PLM tools and systems. The final area, Benefits, shows what kind of benefits you have now of the current PLM support. This will show if you believe that PLM systems help to increase e.g. efficiency and innovation ability. A high score shows that you think that PLM systems are beneficial in general.

4.4.4 Identification of a suitable pilot group for the PLM introduction

In the case study the PLM users were grouped in five different groups where two groups could easily be identified as laggards and as pioneers. The pioneers were in this case the group that would be suitable for a pilot introduction project. A classification of the groups is found in Table 3.

In the following introduction you have to make sure that the pessimists are shown the advantages of the new PLM system, and likewise that the optimists are motivated to change, since they seem to be very satisfied with the current PLM support.

It is important that the study performer handle this information with care since it might compromise personal integrity. In a situation where you do not want to handle personal information, the method could instead suggest a couple of suitable roles or departments that are more suitable than others for a PLM introduction project.

Table 3 Examples of identified PLM user groups

Name/Criteria	Satisfaction	Expectations	Benefits
"Pioneers"	Low	High	High
"Laggards"	High	Low	High or Low
"Pessimists"	Low	Low	Low
"Optimists"	High	High	High

4.5 Step 5: Qualitative Analysis

In the qualitative analysis step, the statistical data and graphs drawn in the previous step are analyzed. From the qualitative analysis it is possible to state groups that are based on indices of satisfaction and receptiveness to change, and which are more or less motivated to accept PLM introductions. Over time, algorithms can be created to calculate different key indices. In the future, several other key indices might be constructed in order to make good assumptions for the needs of each statistically clustered group.

For the study performer, step 5 is an opportunity to gain verification and validation of the results through workshops, and discuss whether the results are in line with the expectations of management, or if these are new findings. It is also important to identify where the PLM users are right, and where they might have a different perception of the PLM situation. Often management knows better what the organization needs than the PLM user.

When a conflict between management and PLM users occurs, it is very important for management to motivate their view in terms that the PLM user understands. For example the PLM vision could be changed to better represent the PLM users problems. If the PLM users sees a problem with "Information quality" it is better to use this as a motivation rather than "shortening lead times" which does not apply as much to the PLM user.

4.6 Step 6: Report Results

The final step of this method aims at making the results usable for the company. The color-coded impact model (Figure 2) is a very good tool in demonstrating the impact and the improvement potential of each area and potential benefit.

It is also possible to present key indices in charts and tables. Individual impact plots using pie charts is one way to show how much each area impacts a potential benefit, which is difficult to read from the impact diagram.

5 Discussion

PLM system introductions have often been done based on a gut feeling of management combined with standardized roll out processes. The methodology presented in this paper can assist management to take better and more informed decisions, which can increase the speed of organizational adoption of PLM tools and systems. This paper provides a number of hypotheses that are not yet validated. For example the belief that the pioneer group in table 3 is most suitable for a pilot project has not been validated. Further future case studies are needed to secure the industrial applicability of the results.

The quantitative, statistical, methods complement the traditional qualitative interviews and surveys often performed in PLM introduction projects. There is always a need for the PLM experts to show the way and to identify the problems that the PLM user is not aware of. This expertise is specifically needed when the survey is validated in the qualitative analysis. The PLM expert will be the most suitable person to interpret and validate the survey. Connecting the survey method to requirement management theory only the outspoken needs are possible to gather through a statistical method. However they can be very efficiently gathered and an image of the current situation in product development can be taken very accurately.

In order to maximize the benefits, stated as objectives, of the survey it is important to do a survey early in the PLM introduction process. It is however also possible to use the method at a later stage, to prioritize resources in a more efficient way.

6 Conclusion

This paper presented four statistical tools that can be used to improve the organizational adoption of new PLM systems and tools. The statistical tools are based on cluster and PLS analysis and results in:

- Identification of improvement areas relating to PLM systems and processes.
- Identification of impacts between the different areas, in order for management to prioritize the most beneficial areas to focus for the introduction.
- Grouping of PLM users with similar needs, so that the roll out of the PLM system can be performed according to the user needs.
- Identification of suitable pilot group for the PLM introduction, to assure a success story for the final roll out.

Further the method enables the organization to:

- Inform PLM users about the forthcoming PLM introduction in a structured way.
- Motivate future PLM users by asking the right questions and making the PLM user think about the forthcoming change and PLM introduction.
- Involve the PLM user in the PLM introduction process at the earliest possible stage, when they still have the possibility to influence and change of the project.

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PLM and design education: a collaborative experiment on a mechanical device

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Abstract: The shift from sequential to concurrent engineering has initiated changes in the way design projects are managed. In order to assist designers, numerous effective tools have been devised for collaborative engineering, which are also well suited to the business world. Faced with these new challenges, practices in design training must evolve to allow students to be mindful of these evolutions as well as to be able to manage projects in these new work environments. After presenting a state of the art of collaborative tools used in product design, our paper presents an experiment focusing on the codesign of a complex mechanical product. This experiment was carried out between two centers of the Arts et Metiers ParisTech School of Engineering, located in Paris and Angers. We analyze the results obtained in this experiment and discuss some ways to improve future projects for inter-centre training programs in design engineering.

Keyword: Design, Education, PLM, Collaborative Design

1 Introduction

One of the most important changes in design habits in the first decade of the 21th century is the phenomenon of Business Process Outsourcing also known as BPO, experienced by various professions [1]. In order to give to mechanical engineering students a first view of the extent of globalization, many Schools of Engineering have integrated within their training programs, design projects involving students as participants [2-5].

The main question from here is : "How can we, as engineering educators, respond to global demands to make our students more productive, effective learners?" and how can PLM help us to achieve this goal?

The Product Lifecycle Management approach to the manufacturing of complex goods is now considered as one of the major technological and organizational challenges of this decade, to cope with the shortening of product lifecycles [6]. Thus, design education has changed in order to provide students with some experience in collaborative design during their studies. Moreover, PLM can also be a solution to face one of the main problems in our educational system: the fragmentation of the knowledge and its lack of depth [1].

Following an analysis of recent changes in the industry regarding practices in product design, we propose a chronological review of methods used in businesses to improve their competitiveness, and describe the challenges these raise for education in engineering design. We then present an experiment carried out in the Arts et Metiers ParisTech School of Engineering, experiment whose goal was to define an optimized environment for collaborative work in design projects.

2 The evolution of design teams in the industry

In a context marked by increasing competition, businesses must suit their organization to the demands of their customers. In this context, the reduced duration of development cycles and the increasing complexity of mechanical systems force businesses to involve actors from various professional and cultural backgrounds in collaborative projects. The organization of design teams has also had to adapt to these changes in the industrial context.

Figure 1 illustrates the changing patterns in the formation of new product development teams as these moved to greater collaboration and virtuality.

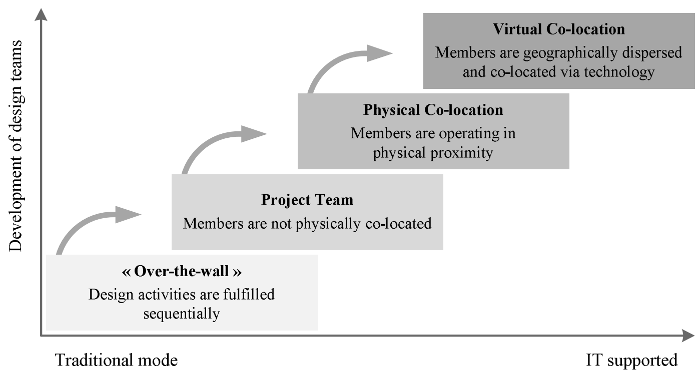

Figure 1 Changes in design teams adapted from [7, 8].

Obviously, these industrial evolutions have been supported by evolutions in work methods and in the associated digital tools. The following section presents a state of the art of these methods and tools.

3 State of the art

In this part, we propose a chronological state of the art of the methods applied in the business world in order to improve their competitiveness.

3.1 Concurrent Engineering

Towards the end of the 1980s and the beginning of the 1990s, two forms of design organization emerged as distinct alternatives: sequential design, which involves carrying out design tasks one after the other, and concurrent engineering, or integrated design [9-11]. Two aspects of Concurrent Engineering (CE) that distinguish it from conventional approaches to product development are cross-functional integration and concurrency. In sequential engineering, exchanges between actors are based on direct relationships. In the CE, one must define common interfaces between the various tasks. Indeed, CE is an approach to product development, in which considerations about product life cycle processes, from product planning, design, production to delivery, service, and even end-of-life, are all integrated. By carrying out all these tasks in a parallel fashion, it becomes possible to reduce the time and costs of design, but also to improve the quality of products.

With the development of Information Technology (IT), CE methods have evolved gradually toward collaborative engineering.

3.2 Collaborative engineering

In the case of collaborative engineering, which emerged in the 1990s, as in the case of CE, overlapping tasks are still present, but project stakeholders are requested to work together and interact in order to reach an agreement and make shared decisions. The degree of collaboration is assessed here by the level of decision coupling. Designers from the whole group work together to design the product, following customers' needs. The project leader, as well as the project group (a group of designers from various companies who have competences and skills in various fields) thus attempt to build and maintain a common view of the problem and solve it together [12]. Collaborative activity is synchronized and coordinated throughout the process of collaboration.

Thus, as synergy is created between project actors in collaborative engineering, PLM ensures that synergy is created throughout the whole of the product lifecycle.

3.3 PLM

In the early 2000s, PLM emerged as a solution to adapt industrial design to the demands of globalization. Indeed, as PLM addresses the entire lifecycle of the product, it has a cross-functional nature and deals closely with the way a company runs [6]. Collaborative design has been the subject of numerous studies. With the development of PDM (Product Data Management), PLM (Product Lifecycle Management) and associated workflows, software firms have proposed solutions to the everyday problems of engineering design departments (versioning of documents, naming etc.). Product Lifecycle Management aims to cover all development stages of a product, by integrating processes and people taking part in the project [13]. This concept is generally used on industrial products. For Amann [14], over the past several years, PLM has emerged as a term to describe a business approach for the creation, management, and use of product-associated intellectual capital and information throughout the product lifecycle. Thus, PLM is an approach in which processes are just as important as data, or even more so. The PLM approach can be viewed as a trend toward a full integration of all software tools taking part in design and operational activities during a product life cycle [6, 15]. Therefore, PLM software packages need product data management system; synchronous and asynchronous, local and remote collaboration tools; and if necessary, a digital infrastructure allowing exchanges between software programs.

Several important challenges, however, must be met if one is to integrate PLM tools within design education.

3.4 Challenges for Design Education

Design education focuses on teaching students how to do design. The key point in design education is to learn how to design.

In engineering education, PLM is a means for students to structure their design methodology. Indeed, before starting an efficient collaboration, students must be mindful of how it works, and how the work can be divided between stakeholders. Thus, from an education point of view, PLM method can be viewed as a sophisticated analysis and visualization tool that enables students to just improve their problem-solving and design skills, but importantly improve their understanding of the behavior of engineering systems [1].

In a globalized world, products are typically, nowadays, designed and manufactured in several locations worldwide. Thus, it is essential to train students to Computer Supported Collaborative Work (CSCW) [16]. Moreover, they will need, increasingly, to use tools, skills, and experiential knowledge suited to 'extreme' collaborative environments. Even for the collaborative design of innovative products, there is an urgent need for specific educational pedagogical strategies and techniques [17]. In the field of engineering, companies and professional organizations expect students to be equipped with a basic understanding of engineering practices, and be able to perform effectively, autonomously, and in a team environment [18]. Traditional design projects (*i.e.* with co-located teams and synchronous work) could reach this aim until a few decades ago, but they are insufficient nowadays.

The experiment presented in the following section aimed to apply the collaborative tools available at the Arts et Metiers ParisTech School of Engineering to a redesign project, in order to derive some pathways for the improvement of an existing collaborative work environment.

4 Experimentation

4.1 Pedagogical approach and experiment objectives

We propose a pedagogical approach based on two kinds of tools: the "engineering toolbox" with CAD and PDM tools to store and share data and the "communication toolbox" with communication tools such as Sametime, Skype, MSN. In the proposed design project, two distant teams collaborate and must face some problems which are partly related to some general aspects of distributed work, such as effective communication, building and maintenance of a shared understanding and conflict management. It is also partly due to the very nature of the design process [8].

An efficient collaboration requires, according to Yesilbas [19] three different types of knowledge: pre-collaborative knowledge, in-collaboration knowledge, and post-collaborative knowledge. Pre-collaborative knowledge is the pre-requisite information, necessary to enter in the project. In our case, pre-collaborative knowledge might include prior knowledge of CAD and PDM tools. A lexicon was also created at the beginning of the project in order to give the same name to the same mechanical parts in the two teams, which constitutes pre-collaborative knowledge. This lexicon was enriched with photos of real mechanical parts, to avoid any ambiguity. Then the in-collaboration knowledge deals with the knowledge that must be shared and exchanged to achieve the action, specifically intermediary representations [20]. In these stages, representations adapted to business constraints must be found to enable effective collaboration. As part of our project, the main IRs generated were CAD parts and “Microsoft Office” documents. Finally, post-collaboration knowledge, *i.e.* knowledge produced after collaborative actions. These were archived as best-practice documents in the database, to capitalize on the solutions found to main technological challenges raised during the project. Once pre-collaborative knowledge was established, the first goal of our experimentation was to evaluate remote codesign activities, specifically to study design activities involving several participants working from several distant sites, using the tools at their disposal to communicate and share data. Next, we analyzed the relevance of these tools, their impact on designer activity, and more broadly on the design process. This was done using questionnaires handed out to the students working in the project. Based on this study, we propose some perspectives for optimizing this remote codesign activity, which have been implemented since.

In the next section, we present the project which served as a basis for this experimentation.

4.2 Presentation of the project

In this section, we first present the context of our study, and then the product whose design served as teaching material in our project.

4.2.1 Context and methodology

Arts et Metiers ParisTech is a School of Engineering composed of eight centers located in France in Aix-en-Provence, Angers, Bordeaux, Châlons en Champagne, Cluny, Lille, Metz, and Paris. The School has developed a collaborative engineering platform aimed at managing innovation projects between its centers. Each center has computer workstations equipped with CatiaV5 (Computer Aided Design software) and Smarteam (Product Data Management software). Students assigned to the project (7 students in our case) have access to the platform and the data it contains. Students also have access to Sametime, which allows sharing and exchanging presentations or work on a whiteboard.

The project, lasting about eighty hours over six months, involved two teams of students in their second year of School of Engineering. Team A, located in Paris comprised three students. Team B, located in Angers (about three hundred km west of Paris) comprised four students. Sessions allocated to the project (twenty working sessions of four hours) did not necessarily take place simultaneously between the two teams. Thus, asynchronous modes of collaboration were implemented. None of the participants had ever completed a design project in remote collaboration. Students were able to communicate using the tools of their choosing. However, they had to design the digital mock-up of the object using Catia and Smarteam software. Following the first "physical" meeting to launch the project, students could communicate by telephone and video conference (via Skype), email, chat (via MSN). At the kickoff meeting, a project methodology was defined. The overall architecture of the database was validated by the two teams and formatted thereafter. This architecture allowed students to easily find and classify their data. The preferred design methodology was as follows. First, a functional skeleton was created to allow each team to position its components in the overall design environment. Then, sub-assemblies were assembled and the overall digital model was created in Catia. The overall schedule was also frozen during this first meeting. The overall project methodology implemented in the course of this project is illustrated in Figure 2 below.

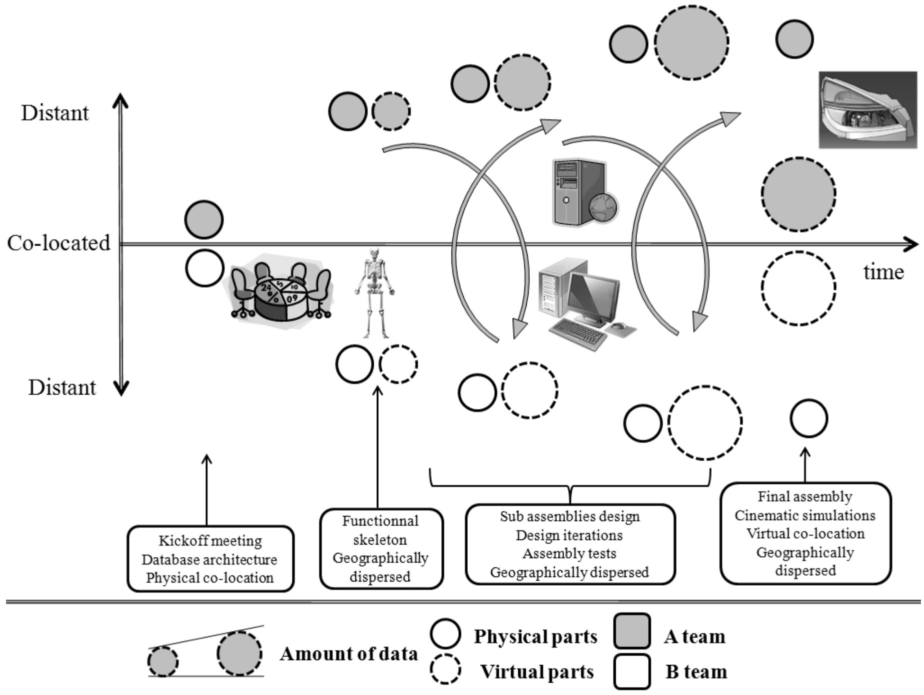

Figure 2 Synopsys of the project methodology

The horizontal axis describes the time line. The two teams (Paris and Angers) met together for the kickoff meeting. The database architecture in Smarteam was defined and the physical parts of the headlight were distributed between the stakeholders. Then, students remotely produced the functional skeleton of the product, i.e. the functional surfaces useful for positioning its parts in relation to each other. The dot-lined circles represent the number of "virtual parts" created. Third, sub-assemblies were designed (using traditional CAD and RE methods) and assembly tests were carried out. Final assembly and cinematic simulations were carried out remotely, but with virtual colocation for the final presentation.

This experimental methodology describes a first stage of the process, based on a pilot project which aimed to remove technological obstacles. We are currently carrying out more work to generalize our findings to larger-scale collaborative work projects, involving greater numbers of students.

4.2.2 Product to design

The project is a Reverse Engineering (RE) project. RE is a vast domain in which products are digitized in order to create a Digital Mock-Up (DMU) on a CAD tool. RE approaches are widely used in competition analysis or when integrating handmade prototypes into a global DMU [21]. The study of RE methodology is therefore important for future engineers. The product to design is a directional headlight that equips top of the range

Renault vehicles (see Figure 3). The headlamp is made of a block that performs the logical functions, and includes the low beam headlight and directional headlight located at the bottom. From a real directional headlight, the objective was to achieve the design of this mechanism through a collaboration between the two teams, using the "collaborative" and "engineering toolboxes". The DMU was then animated to visualize the trajectory of the light beam on CAD software, according to the input references, *i.e.* mainly the angle of the steering wheel. The project began with a stage aiming to structure the team [22]. The distribution of the parts to redesign between the two teams could be considered according to two modes: either a functional division, leading to design modules associated with functions which are then assembled together, or a division based on the local expertise of stakeholders, which suited well the needs of such a short project. For example, surface reconstruction from a 3D data cloud, which is necessary to design the frontal pane of glass, requires expertise that was only present in Paris. For this reason, the second alternative was chosen.

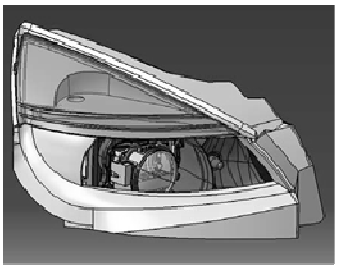

Figure 3 Final assembly DMU of the directional headlight

Collaboration in this project was analyzed in order to identify the limitations and the difficulties encountered by our students. In the next section, we present the results of these analyses as well as the pathways for improvement which we chose in order to optimize the collaborative work environment provided to our students.

5 Results

Data relating to collaboration were identified by a method of semi-structured interview. The interviews for Team B took place in conference calls, those for Team A were held face to face. Two series of interviews were carried out. All participants were interviewed in French, recorded and analyzed subsequently. General impressions about the project, shared at the final defense, were gathered and recorded in video.

Questions posed in the first interview concerned three topics. First, the ease with which participants "got to grips" with the tools at hand. Then, the types of intermediate representations (IR), which are every representation which appears during the design process, from its beginning to its end. [20], and collaborative tools used throughout the project. And finally, a question at the end of the interview allowed students to express an open opinion regarding which criteria should be used to improve the working environment and collaboration.

The second interview allowed us to use the criteria thus identified by the students, to establish a list of high-priority actions to improve the collaborative work environment. A choice was made to focus on the three sources of dissatisfaction most mentioned by students.

After analyzing the data collected in these interviews, we present the results of the collaborative activities carried out in our project. We also propose some paths for improvement, in defining an optimized software platform to support collaboration in design education.

5.1 The collaborative project

During the collaboration in the project, the collaborative tools that were used by the students were: email (86%), chat (71%), videoconference (100%), DMU or paper documents (86%) and PDM (Smarteam, 71%). A recent study by Brown [23], on a panel of one hundred companies shows that the main technology enabler for design collaboration is e-mail, still used in 95% of cases of collaboration far ahead of PDM or DMU tools. It also shows that 87% of the best performing companies in terms of time and development costs have used collaboration tools in design for over a year. Figure 4 presents a comparison between this industrial study and our project.

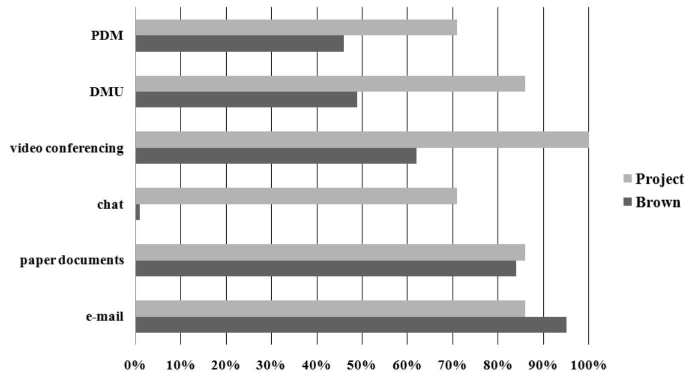

Figure 4 Use percentages for various collaboration tools, comparing Brown's results [23] with those from our project.

The industrial practices in design collaboration observed by Brown and by ourselves are broadly similar. Firstly, email remains a widely used tool. Given the nature of our design project, which focuses on mechanical engineering, we noticed that DMU tools were more often used in our study than in Brown's.

Secondly, in the student project presented in this paper, a large part of collaboration relies on chatting software, partially explaining the less frequent use of email.

We also noticed that not all students used the collaborative platform, possibly suggesting that the platform is not easy to use. To the first question "What is the first thing you need to start making the most out of Smarteam?", 71.5% of the students answered that they needed a tutorial to start. A tutorial was provided, consisting in a training exercise where the various stages in the design of an example product were described one after the other. This tutorial allowed students to get to grips with the software on his/her own. In case of setbacks, a video of the design sequence was available on each computer connected to the platform.

During this experiment, students only had access to the database when they were physically present in project meetings. In other words, they were unable to freely access project data outside of the hours allocated to this work. This also was perceived as a strong obstacle to collaboration. Of the five participants which used PDM, all expressed the wish to access the software from home, mainly to be able to exert some control over the progress of the project, since working hours differed between the two centers.

One final obstacle to a more widespread use of Smarteam was the time needed to work on data stored in a vault server based in the center of Châlons-en-Champagne. Connecting times to the environment and file loading times were assessed as either long or very long, by 28.6 and 42.9% of participants, respectively. Next, five of seven students remarked, in the open question at the end of the interview, that just one face to face meeting at the beginning of the project did not allow them to create human bonds and work methods that were robust enough. There is a need for students to spend more time in co-localization (*i.e.* in the same location) in the beginning of a project. To achieve this, drawing inspiration from the physical environments used in large-scale industrial projects, we suggest planning project work sessions over a period of two full days, dedicated to setting up the methods and tools of collaboration, as well as to fostering team spirit between the students.

Finally, we listed the main criteria identified regarding the resources available to students for collaboration. In the next section, we present the results of the second interview, which allow us to prioritize the implementation of the proposed improvements.

5.2 Towards defining an optimized platform for collaboration

Following the early results presented above, the results of the second interview suggest two main pathways to improve the current PLM environment. Indeed, three main criteria for dissatisfaction have been identified:

- inability to remotely access project data, outside of the dedicated locations (71.5% of subjects were dissatisfied),
- ergonomics of the user interface (57.1% of subjects were dissatisfied),
- overly lengthy transfer times: file transfer times (71.5% of dissatisfied users) and connection times to reach the work environment (42.9% of dissatisfied users).

In order to propose a collaborative environment that is well suited to our needs for design education, we strove to address these various sources of user dissatisfaction, which might hinder the use of this platform. This improvement task involved an intercenter task force. We present below the results of its work.

First of all, due to confidentiality issues regarding the industrial projects, coupled with issues surrounding network security, we were unable to implement network access from outside the designated sites.

Second, to address the issues surrounding user interface design, we added a compulsory four-hour training session for all students, added to the tutorials that were already available online. This prior training allows students to become somewhat familiar with the tools proposed in the engineering and communication toolboxes.

Finally, we modified the architecture of the national data, network, in order to significantly reduce transfer times. To achieve this, we replicated some data, which up until now was centralized on a single nationwide server, to all other servers. As a result, file transfer times lowered by approximately 50%. Finally, the network architecture requires that software licenses be stored on nationwide server, which lengthens connection times. One should note however that students only connect to the server once per session, at the beginning. One might therefore consider that these delays are less of a hindrance than file transfer delays in the design process.

In short, several actions were undertaken in order to allow optimization of the collaborative work environment provided collaborative design. Much effort remains to be made, however, in favoring work sessions carried out synchronously in several locations.

6 Conclusion

Due to worldwide competition between companies, practices in design training must evolve to allow students to gain mindfulness of evolutions in design practices as well as to manage projects in these new work environments. The Arts et Metiers ParisTech School of Engineering has adapted its courses and design project methodology in order to fulfill these needs. After having presented a state of the art of collaborative tools used in product design, we presented an experiment focusing on the codesign of a complex mechanical product. We created synergies between several training centers; and provided a detailed analysis of collaborative design activity. Keeping in mind the need for data security, we nevertheless were able to respond to many sources of stakeholder dissatisfaction in this pilot project. As prospects for future research we note that this optimized environment should be tested using a new experiment in a co-localization condition, allowing students to apprehend the concept of work flow using real life industrial examples.

Acknowledgments

The authors would like to thanks Ms Andia Montes C. and Mr Nelson J. for their helpful suggestions received during this experiment.

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Chapter 3 Sustainability

Integration of sustainability in NPD process: Italian Experiences

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Abstract: Decisions that are made during NPD process lock-in around 80-90% of a product's life cycle sustainability performances. Therefore, investigating how companies are integrating sustainability in their NPD process is the main target of this paper. From literature, a three pillar framework (Strategy-Tool-Process) has been developed that outlines "a must to have" elements to successfully integrate sustainability and life cycle thinking in NPD process. Based on the framework a questioner has been developed to assess manufacturing companies operating in Italy in Electrical, Mechanical, and Automotive sectors. The empirical study was conducted on 10 companies which have high innovation cycles and are the target of many product based EU legislations (e.g. WEEE, ELV, EuP, REACH, RoHS, and others).

The results show that companies still consider sustainability as a constraint rather than opportunity for eco-innovation. Moreover, companies are trying to meet the minimum requirements asked by legislations, despite the efforts made by academia to drive strategic push, effective tools, and suitable NPD process paradigms to foster sustainable product innovations.

Keyword: Sustainability, Lifecycle Thinking, NPD (New Product Development), Eco-design.

1 Introduction

Sustainability has three main pillars: Environmental, Economic and Social aspects. In the last couple of decades, significant research works have been carried out in order to investigate different ways of supporting manufacturing industries in the development of more sustainable products and processes. Certainly, this consciousness regarding sustainability problems and the knowledge about different tools techniques are increasing in the industrial world. The development of more environment friendly products leads designers to take into consideration sustainability aspects in concurrence with traditional technical and economical aspects since the beginning of design activities.

Researchers are pointing out that Product design and Development is a decisive stage among any part of a value chain in reaching sustainability objectives. (Bowman 1996, Fiskel 1993, 1994, Shane J. Schvaneveldt 2003, Design Council 1997, Devanathan S. 2010) and the EU report (EU commission website, 2010) declared that decision made during design determines around 80-90% of product's sustainability performances. However, the support needed for making sustainability related decisions are not systematically integrated in companies today. So, it is a necessity to systematically categorize and understand the main enablers that help the integration of sustainability aspects in during NPD process.

With this aim in mind, this paper first aimed at investigating literatures to develop a framework of enablers to successfully integrate sustainability in NPD, which is explained in Part 2. Then, a questioner consisting of 26 questions has been developed based on the framework. The survey was conducted on 10 international manufacturing industries that are developing products in Italy. Since the sample size of the study is quite small the study should be considered as a fact finding study rather than a comprehensive one. More details on the methodology followed for the studies are explained in Part 3.

Finally, in Part 4 results found in the study and some insights are outlined as a recommendation for further studies.

2 State of the art and framework for integrating sustainability in NPD

2.1 State of the art

Many studies have been conducted for a while to integrate sustainability in NPD. In this study literature published in the last 17 years (1995-2010) have been studied, including academic journals, books and conference proceedings, to understand what have been written and practices in literature and industries till now to integrate sustainability in NPD. In particular, enablers that help to successfully integrate sustainability in NPD have been given attentions. The enablers have been categorized in to three pillars; strategic approach of sustainability in NPD, supporting tools, and process paradigms that foster efficient and effective integration of sustainability in NPD, as shown in the Figure 1 below.

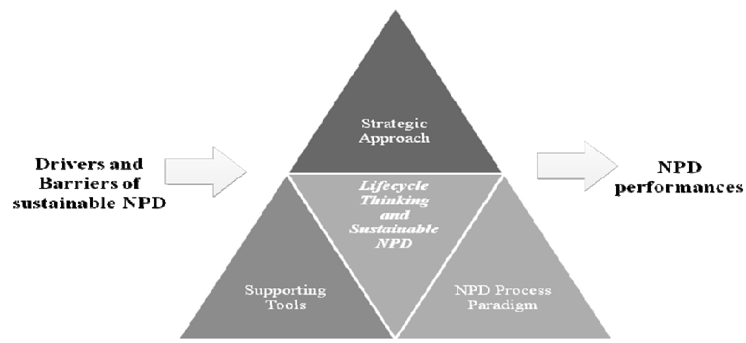

Figure 1 Framework of enablers for successful integration of sustainability in NPD

In the following sections the summaries of state of the art in these three dimensions are given.

2.1.1 Strategic Approaches: Align sustainability in NPD with corporate goals

It is of all our doubts that companies which aimed at providing goods and services for profit to take care of sustainability matters while developing their products. In general, companies afraid the so called "'irreversible green mistakes'" and have doubts on investing on sustainable products (Rugman and Verbeke, 1998). The reason is that innovation on sustainable technologies and products need a long term investment and strategic view; a process where the outcome is always uncertain. In addition, incorporating eco-innovations presents companies with key challenges, which in themselves are subject to different managerial perceptions and interpretations of inter alia technological and market potential, regulatory constraints and firm-specific capabilities (Kolk and Pinkse J. 2005; Sharma, 2000), and trade-offs have to be made between making economic profit and social/environmental good. However, as sustainability goes to the mainstream companies should strategically plan and invest on the sustainable products and technologies to gain competitive advantage, and can leverage sustainable value by managing the whole life cycle of their products.

The willingness and commitment of top management and strategic alliance of sustainability in NPD is paramount to insure that operational activities are in place to support seamless integrations of sustainability in NPD (Melnyk, S.A, 2001, Fiskel 2009, Robert Sroufe,2002); such operational activities could be technology selection, development and deployment, suppliers integration and selection, investment on eco-innovation across the value and other initiatives that could go beyond the company boundaries.

Therefore, if successful integration of sustainability is sought then companies should have long term perspective on their investments on R&D innovation, and other initiative that guarantee the development of sustainable products. Moreover, companies should develop capabilities and resources to face the challenge and put on the market sustainable products.

2.1.2 NPD process paradigms

To design any product designers should follow some set of rules, procedures or in general process. The type of process they follow depends on the type of products and the company's business strategy. Meanwhile, the processes a company follows affect the product's quality, and performances in terms of time-to-market, innovation and development costs (Ulrich 2000). Moreover, the structure of a design and development process affects the sustainability performance of a product to be designed (Melnyk, S.A, 2001, Sophie Hallstedt, 2006).

Traditionally, NPD process is generally structure in a sequential manner or called serial engineering (Copper 1991). Sequential design process models are characterized by freezing design specifications early in a design process so that designers have a single design options to discern till it reaches a control gates. At design gates the design concept will be tested if it meets design requirements, and at that point if the design doesn't meet the requirements either design iterations or sub-optimal product will be the result. The most adopted and prominent sequential model is stage-gate-model or phase-gate model (Cooper 1991, 1995, 2008).

As mentioned above, in such process models companies first decide the fate of the product early in the process, and problem will be revealed latter at the design gates. If sustainable or green products are to be design following such the process paradigm two problems will happen (Melnyk, S.A, 2001); the first one is that, if the designers found that the product does not meet some environmental requirements at latter design gates they need to redesign again, which in turn affects time to market and incur additional cost for the company. The second problem is that since environmental considerations are taken secondary in industries, once environmental problems have been found at the gates designers over look the problem and prefer to lunch sub-optimal products from sustainability perspectives.

Concurrent engineering (CE) was born to improve the problem of serial engineering approach of NPD process (Barkan 1988; Evans 1988; Winner et al.1988). In CE manufacturing engineers intervene in a design process to consider and improve the manufacturability of the design. Such NPD paradigm is more effective in addressing sustainability issue than sequential paradigm (Hallstedt, 2006). Responsible partners along the product life cycle can come together and alleviate potential sustainability problems starting from the early stage of a design (Hallstedt, 2006, Lisa M.E et.al, 2008).

Therefore, successful integration of sustainability in NPD depends on how NPD process is structured in a company. This phenomenon has been a focus of investigated in this paper across the surveyed companies.

2.1.3 Supporting Tools

Many efforts are made to develop tools that support integration of sustainability in NPD, in fact, this is the one that have been investigated in literature so extensively comparing to the other two enablers identified in the framework.

Many the so called eco-design tools and methods exist (Devanathan S. 2010): some are extremely simple and qualitative (such as checklists), while some are complex and quantitative (Such as LCA), and others based on QFD (such as Green QFD). The selection of the best tool for a given application depends on the individual situation of the context of the design and development process.

Mistakes in selecting the most suitable tool depending on the specific situation may limit the effectiveness, usability and applicability of the tools. Criteria that should be taken into account during the selection of the adequate tools could be: the quality of the expected results, the aim of conducting the study, the time available, the type of business or product considered, the intended user, the design stage a tool is intended to be used (i.e. concept stages, system design level, embodiment design, and detail design) (Sakao and Fargnoli, 2008).

In this study we have considered around 30 eco-design tools that have been found in literature. Then, for each tool we have outlined the following queries; when to apply, where to apply, how to apply, who should use the tools, why to apply, for successful integration of sustainability in NPD. Finally, this information are asked for the interviewee companies to understand; first, whether they are applying these tools, second how effective and efficient are they in applying the different tools identified.

3 Methodology followed

The study is a fact finding study, aimed to understand the main motivations, limitations, effectiveness of integrating sustainability in NPD from strategic, process and tool perspectives. To attain the objective 26 question have been developed. The structure and the summary of the questions are categorized as follows.

A. Questions about drivers/barriers of sustainability integration in NPD (4 questions):
   - o The stimuli factors considering sustainability in NPD
   - o Barriers of incorporating sustainability in NPD
   - o Causes of Eco-design projects failures and successes.

B. Questions about enablers of integrating sustainability in NPD:
   - I. Strategic focus (11 questions)
     - Commitments of top management
     - Definition and boundary of sustainability in NPD (e.g. lifecycle thinking, short term oriented)
     - Level of investment on sustainable solution in NPD comparing to total R&D budget
     - Mandatory and voluntary sustainability polices and legislations the company is adopting
     - Sustainable product strategy and level of innovation adopted (e.g. product improvements, product redesign, new product concepts, new technological solutions etc.)
     - How the company handle the tradeoff between traditional NPD performances such as cost, performance, quality, time to market with respect to environmental and social issues in NPD.
   - II. NPD process paradigms (4 questions)
     - Coordination of other functions during product design such as manufacturing, supply chain partners, products' end-of-life partners (dismantlers, recyclers, waste stream collectors etc.)
     - The systematic integration of sustainability issues throughout a design process (product planning phase, concept design, embodiment design, testing and prototyping, and detail design)
     - Products' life cycle considerations (from material extraction to manufacturing, to logistics and to end of life phase)
     - Exploration and utilization past projects' knowledge.
   - III. Supporting tools (7 questions)
     - Types of sustainability design tools used
     - The criteria to choose specific tools
     - The impact of using sustainability design tools on the NPD performances.

C. Questions about the performance benefits/losses due to integrating sustainability in NPD (3 questions)
   - o Financial and non-financial benefits gained (e.g. profits, cost reductions, new markets, brand image etc.)
   - o Impact of integrating sustainability on the traditional NPD performances such as time to market and project costs
   - o Internal changes due to sustainability consideration in NPD (e.g. motivation of designers).

Multiple questions have been developed for each groups of the above lists, and asked for the case companies. The results and discussion of the study is elaborated in part 4.

4 Results and Discussion

As explained in Part 3, the questions are organized in three parts. A) Barriers/drivers B) Enablers (Strategic focus, Supporting tools, and Process paradigm) and C) Impact of integrating sustainability in NPD on NPD performance measures. The discussions of the results are also discussed in this structure. In the first part of this section, barriers and enablers companies are facing to consider sustainability and life cycle thinking while design new products will be discussed. Then, the level of applications of enablers in the industries while designing new products will be discussed. Further, the impact of incorporating sustainability on NPD performances will be discussed in detail. Finally, concussions and further research will be outlined.

4.1 Drivers and Barriers of integrating sustainability in NPD

Companies doing sustainability in NPD could have many reasons or drivers to do so. Among them are; long-term innovation opportunity, reduction of the environmental impact (commitment to reduce the environmental impact), image improvement, reduction of costs and new market opportunities are reasons given by companies interviewed. However, companies' respond as their commitment to reduce environmental impact here might not reflect the reality as they tend to show/think their companies more committed than they actually are. In reality, most of the decisions and interest depend on either costs or long term plans as image improvement and entering to new markets.

From the study it has been found that companies are feeling responsible for taking sustainability consideration in developing new products. However, they mentioned that the lack of time and budget to discern sustainability (in terms of investment in new or modified technologies, materials and so on) in NPD the most important barrier. Indeed they frequently reported that unless and otherwise government legislations forced them they won't spent time and money in doing sustainability in NPD. Apart from these, some companies believe that investing on sustainable (e.g. redesigning product) as "fruitless", without financial gain.

Although in theory product design and development is the most important intervention point to achieve corporate sustainability goal, those who are directly involved in design process have little awareness on this important point. And, they still have doubts design brings more sustainable leverages than for example end of pipe solutions (pollution prevention solutions). Moreover, resistance to change by engineering staffs has been mentioned as a relevant barrier in integrating sustainability in design and development process.

Most eco-design projects fail for two main reasons according to the industries interviewed. The first one is due to availability of sufficient information and knowledge about the impact of complex product systems on the environment and society. The other one is the existence of many uncertainties in developing sustainable products such as: Suppliers' compliance issues, integrating manufacturing capabilities, and uncertainty about the market acceptance of the product by the customer. Although these reasons are obvious, dealing with supply chain and life cycle uncertainties should be given proper attention for eco-design projects' success.

4.2 Enablers of integrating sustainability in NPD

The study in this category has been classified into three main enablers identified; strategic focus, process paradigm supporting tools. The report is organized in a similar fashion:

4.2.1 Strategic focus

Most of the companies interviewed have the following high level sustainability programs; CSR (corporate social responsibility) strategic scheme, ISO14001 EMS (Environmental management system), and EH & S (Environment, health and safety) polices. This shows that top managements are also committed for overall sustainability of the industries. However, when it comes to the ground level, as of NPD, there is no evidence that sustainability is properly integrating in top-down approach. To better understand if top managements have genuinely cascaded sustainability to NPD, other questions have been asked such as; if they integrate sustainability in NPD, the definitions of sustainability in NPD, level of investments, type of voluntary initiatives considered, the consideration of products' life cycle phases, and how tradeoffs between traditional performances (cost, quality, functionality) are considered compared to environmental and social once, and finally they have been asked the type of eco-innovation they follow.

Almost 90% of the companies responded that they consider sustainability in NPD. But, the definitions of sustainability differ from company to company, and most of them take sustainability and environmental consciousness as same without a comprehensive approach of sustainability as the balance between Economic-Environment-Social dimensions. This can be seen by taking some of the definitions of sustainability in NPD given by the respondents:

- *"Ecodesign of the products assisted by Life Cycle Assessment and integrated in our environmental management system"*
- *"Product design and development are compliant with a global sustainability approach, aimed to: Reduce CO2 and polluting emissions, Increase recoverability, recyclability and reusability of vehicle, Continue to improve product safety".*

It was possible to check strategic alliances of sustainability in NPD by asking how tradeoffs are handled between Economic considerations (cost, performance, and functionality), Environmental and social considerations. And, it seems that companies are considering sustainability in a balanced way although high priority is given for economic considerations (about 50-60% importance comparing to environmental (30%) and social once (20%)).

The level of investment for sustainable innovations shows that only 5-10% of total R&D budget is invested in average. This figure cannot be taken as absolute measure since 5-10 % might huge for one industry and small for other. But, the type of sustainable innovations somehow shows that companies mainly focus on product upgrading or redesigning than investing in new and more sustainable materials and technologies. Furthermore, almost all companies interviewed are adopting only mandatory EPR (extended product responsibility) EU polices such as REACH, RoHS, ELV, WEEE, EuP respectively, which ask only minimum requirements to be fulfilled. In fact, companies have reported that there are no significant challenges in fulfilling these minimum requirements. This shows that companies are not taking sustainability issue as means of voluntary innovations rather it is a minimum mandates they need to comply with.

4.2.2 NPD process paradigms

This part aimed at assessing how companies have organized their NPD processes in such a way that sustainability is effectively integrated in NPD. For this different questions have been asked such as; functional coordination during design, life cycle orientation and evaluation of products, integration of sustainability targets at different phases of design, and the usage of knowledge from past product development projects.

Although, it has been difficult to evaluate how concurrent engineering (CE) is applied for sustainable product development, there have been evidences that multiple functions (e.g. manufacturing, marketing etc.) step in during design to suggest and evaluate product concepts from the beginning. One of the companies interviewed has the so called “Green stage-gate-model”, where the manufacturing department comes in at different control gates and check if manufacturability as well as sustainability of the product concept from manufacturing perspective is addressed. However, little evidence has been found about the involvement of multiple stakeholders in NPD to design sustainable product, in particular those who are outside the companies (e.g. suppliers, dismantlers, recyclers etc.).

Many companies reported that they have life cycle view of the product they are designing, they consider all except logistic phase of a product life cycle (material extraction, manufacturing, use, and end of life phases). In particular, manufacturing is given high priority to be considered in design. This could be from the fact that CE is almost applied in all companies now days, and it is easy to coordinate and evaluate the manufacturing phase compared to other parts of the life cycle phase.

In general, companies have no means of using past product’s knowledge to be used for future product development. This might hinders the continuous knowledge development inside the company about products’ sustainability performances.

Importantly, companies responded that they consider sustainability issues mostly at embodiment design phase (60% of the time) and detail or prototyping phase (30% of the time) and never at concept development stage. This gives an interesting insight, because designers have a lot of potential for sustainable innovation at concept design but they don’t consider it at this phase. Moreover, design arrives at embodiment stage or prototyping stages after committing a lot of resources (time, cost). If sustainability targets are not met at these phases, designers tend to ignore them and prefer to launch inferior products, since sustainability requirements are considered as something additional comparing to time to market or cost. And, even if designers want to improve the sustainability performance of the design, they need to re-iterate the process, which in fact is additional waste of time and cost.

4.2.3 Supporting tools

This is among the enablers academia has been trying to develop for so long. Many design supporting tools in the name of eco-design tools or DFX (design for X) tools have been developed. However, it is the time now to assess how and why these tools have been adopted in industries.

Although the selected companies have claimed that they adopted sustainability for so long (5-10 years), only six out of the ten companies adopted ‘proper’ eco design tools ranging from simple checklists (e.g. Banned material and chemical lists, disassembly lists and so on) to full or simplified LCA tools.

Companies have multiple criteria to choose among tools, and the important once are: easy to implement and easy to learn, delivering accurate results, less the amount of required information, need less resources for the assessment. From this one can understand that sophisticated eco-design tool have little importance to bring sustainability to the mainstream NPD practices. The main challenges will be how to modify effective tools such as LCA so that companies can use adopt it in a day to day process. Moreover, there is a need to disseminate and introduce such tools to industries.

4.3 Sustainable NPD and performances

Till now, the main drivers and barriers companies have to develop sustainable product have been discussed, and then the main enablers to integrate sustainability in NPD. Now, in this section the impacts of integrating sustainability issue on traditional performances are investigated. This is a crucial issue, since it is seldom that companies worries about sustainability issues if it jeopardize the traditional NPD performances such as time to market, development cost, and quality.

Companies interviewed stressed that to fully integrate sustainability in NPD projects it cost them more than the gained they could have achieved. Moreover, time to market could be extended if sustainability issues are addressed effectively. As mentioned above, the reasons are either internal problems (lack of designers' knowledge, eco-design tools are time consuming, new innovations in terms of material and technology take time and huge investments).

But, they also stress that non-finical gains have been achieved such as; new skill and competencies, company image, customer acceptances, and overall sensitivity towards environmental impacts have been raised inside the company. Therefore, the main issue here is how to structure NPD strategy, tools, and process in such a way those traditional NPD performances are either unaffected or even improved.

In summary, the developed framework can easily be used to evaluate how sustainability is effective and efficiently addressed in NPD in manufacturing industries. And, as seen from the 10 Italian cases the consideration of sustainability is not matured enough to attain the general sustainability goal expected by multiple stakeholders. For that, academia should not only focus on developing sophisticated tools but also on need to investigate new way of NPD process structures and to better align strategy objectives with sustainability goals.

Further reaches should be done taking more cases and samples to better understand the maturity level of integrating sustainability in new product design and development.

Acknowledgment

This work was partly funded by the European Commission through the LeanPPD Project (NMP-2007-214090, www.leanppd.eu). The authors wish to acknowledge their gratitude and appreciation to the rest of the project partners for their contributions during the development of various ideas and concepts presented in this paper.

The authors further would like to make a special acknowledgement for Ms. Gokan May and Ms. Ezgi Helvaci for their contribution for making company interviews and surveys.

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Contribution to sustainable product development by means of knowledge assets integrated into a PDM System

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Abstract: This paper describes the need of sustainable engineering derived from the principle of sustainable development. The main goal is to present a new approach where knowledge, especially sustainable product and process knowledge, can be organized and provided efficiently for the user. This is type of a straightforward approach. Earlier work results are directly included and experiences from basic and applied research are transferred. The knowledge is deposed in knowledge assets which are assigned to the product structure. The solution approach is implemented into a Product Data Management (PDM) system. Eventually, a case study provides an overview of the approach's benefits.

Keywords: Sustainable Product Development, Design Process, PDM System, Knowledge Management, Knowledge Assets

1 Introduction

The implementation of the concept of sustainable development requires, among other issues, the use of appropriate methods and tools in product creation processes. Nowadays, engineers have to rely mainly on their product knowledge even though various tools and approaches for sustainable product creation are developed and investigated in academia. Incorporating sustainability issues into design considerations requires the integration of product-related sustainability knowledge into the working environment of the engineer. In particular, companies have to practice an effective and efficient knowledge management. For this reason, many companies launch sophisticated knowledge management systems beside other engineering tools and thus operate several complex and care-intensive systems. In addition to high maintenance costs this causes additional work for the engineers who constantly need to switch between different systems. Figure 1 provides an overview of the current IT working environment in engineering.

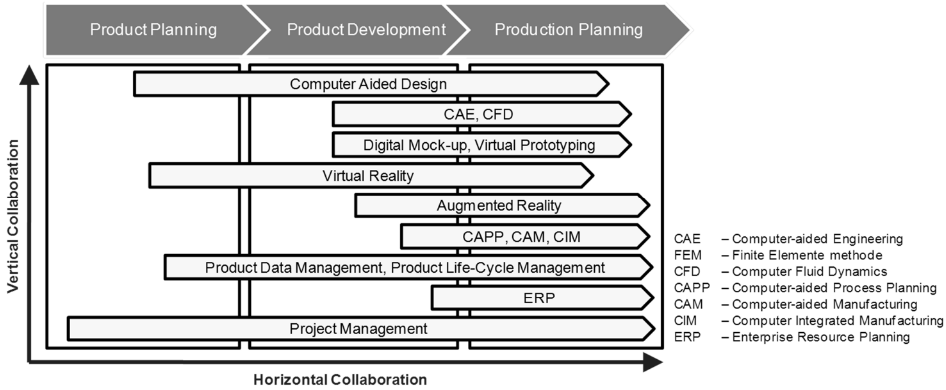

Figure 1 IT-support across the product development process [1]

The systems have BOM (Bill of Materials) or product structures as a backbone of product information retrieval in common. Within a Product Data Management (PDM) environment a product structure can be organized efficiently as logical dependencies between different product elements can be established. In doing so, a product's complexity can be handled efficiently along the different IT systems of a product development process.

This paper presents how knowledge, e.g. about the product, organization, design methodology, can be provided in product development processes effectively for the user. For this reason, the creation of transparency of the product to be developed is an essential step for knowledge management. Knowledge is needed about both the structure of the entire product and of the individual elements of the product. Additionally, an approach how knowledge can be prepared, represented and visualized in a suitable way is shown. Finally, the product structure combined with a transparent knowledge structure is a first step towards integrated knowledge management in the field of product development processes. Basically, this paper presents an approach on how knowledge assets, especially sustainable knowledge assets, are characterized and how they are integrated into a PDM system. The basic idea of our approach is the coupling of knowledge to the product structure. In doing so, a structure of knowledge in product development is given. Hence, knowledge is directly integrated into the actual working environment of the engineer in order to support (sustainable) decision-making in design processes. Moreover, these systems are mostly rejected by the employees, for whom the new system at a first glance is perceived as a higher workload. On the other hand having fewer systems running saves both maintenance costs and human resources.

2 Research approach and need for sustainable knowledge

2.1 Research questions

The main goal of this approach is to develop a new approach for knowledge organization and allocation, especially for sustainable product and process knowledge, in engineering design. For this purpose, the following research questions are pointed out:

- How can the engineer be qualified to contribute to sustainable value creation?
- What kind of (sustainable) knowledge is needed?

- How can the (sustainable) knowledge be organized and provided?
- How can customized IT systems facilitate the engineer's work?

The following chapters describe the way from the principle of sustainable development to the need for sustainable design knowledge. It demonstrates the current situation in engineering design when it comes to knowledge acquisition and application to design projects and provides a suitable example from practice.

2.2 Sustainable development and sustainable product development

The World Commission on Environment and Development (WCED) defined sustainable development as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2] already in the year 1987. The ecosystem of the earth and its natural resources form the basis for the fulfilment of human needs. Basically, resources form the basis of an extensive value chain whereas at the end products are designed to serve human needs. In order to maintain living conditions for future generations product development thinking has to be changed. To cope with the WCED principle of sustainable development, product development must create products with fewer resources and, at the same time, increase the product's value [3]. Thus, not only the product itself must be considered but also its value-adding environment, which consists of processes along the entire lifecycle.

In fact, there exist many definitions of sustainable product development. All of them are based on the principle to align economical, ecological and social perspectives. Against the background of legislation and a growing awareness among the customers regarding a sustainable lifestyle the manufacturer‘s responsibility of its products grows throughout the product lifecycle [4]. Since essential properties and characteristics of products are already determined in the (early) stages of product development, it is necessary to integrate sustainable aspects into the product development process. Nowadays, product developers rely on their product knowledge and methods in order to evaluate the impact of design alternatives on the product lifecycle. But due to increasing product complexity and diversity this mission is rather impossible and one depends on supporting methods and tools.

2.3 Sustainable value creation

Value creation is the basic intention of today's globalized production-oriented companies. Against the background of pure economical value creation, the principle of sustainable development refers to lifecycle thinking and thus lifecycle value creation.

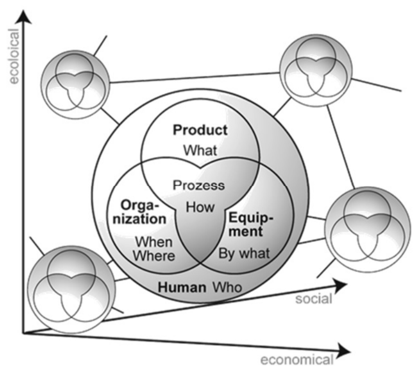

Figure 2 Factors of sustainable value creation [5]

From a production-oriented perspective, Seliger suggests the concept of sustainable value creation networks [5]. A value creation network consists of horizontally and vertically integrated value creation modules. Value adding tasks are divided among each value creation module according to different criteria which can be found in the factors of value creation. The factors of value creation represent the factors of industrial value creation which are inseparable tied to each other. These are products, processes, production equipment and organization as well as the humans involved (Figure 2). Hence, sustainable product knowledge can be deduced from the factors of value creation.

2.4 Multi-objective design

Due to the complexity of today's products a multi-objective satisfactory design including not only physical performances but also sustainable aspects is necessary. When it comes to sustainable product development, decision-making at the early phases of design regarding economical, ecological and social aspects is important. Moreover, the sustainable product development contains multiple sources of uncertainties. Therefore, specific product and process knowledge of the entire lifecycle is of great importance. Various approaches for sustainable product development have been developed so far. The approaches can be classified into checklists and guidelines (e.g. material checklists, guide for environmental improvement [6]), rating and ranking tools (e.g. pre-specified scale system [7]), analytical tools and software systems (e.g. Life Cycle Assessment (LCA) through GaBI Software). However, the approaches require detailed knowledge in product design as well as manufacturing processes and logistics. This aspect can be confirmed by the authors of this paper who run several field and research projects, e.g. the previous series of our studies had proposed a preference set-based design (PSD) method that enables the flexible and robust design under sustainable aspects while incorporating designer's preference structure at the early phase of design. The proposed approach to sustainable product creation based on the PSD method offers the possibility to obtain the multi-objective satisfactory solutions beyond technical performances incorporating sustainable issues as well [8]. Eventually, well organized and specialized knowledge is necessary to proceed through the engineering and sustainability assessment processes.

2.5 Need for transparent (sustainable) design knowledge

Industrial practice and research projects have shown that it is very complex to develop sustainable products. The following case exemplifies this issue by means of the development of a sustainable alternator. Knowledge, information and data about the alternator design, development process, manufacturing process and logistics have to be gathered and deployed. Table 1 lists an impression on the required knowledge, information and data input.

In fact, the development project of the alternator was very time consuming due to heterogeneous data and information sources (such as literature, information from the Internet, documented fragments of activities and data of previous developed alternators as well as gathering knowledge from engineering and environmental experts). Additionally, the sources were distributed over different data sources and IT systems having partly incompatible data formats. From the engineering point of view the need for a transparent way to integrate knowledge into one system and at best into the actual working environment arises. Having the right knowledge at the right time under the right conditions at the right place for the right client (referring to the seven rights of logistics by Plowman [9]) must be guaranteed when it comes to sustainable product development. The authors of this paper suggest integrating so-called knowledge assets into a PDM System in order to accomplish the above mentioned demands.

Table 1 Required knowledge, information and data input for alternator design (derived from [8])

Knowledge, information and data input	Specification (examples)
Development process	Sequence and dependencies of design and engineering activities
Dimensioning the alternator design	Calculation of performance based on height of stator and rotor coil
Establishing a list of sustainability indicators	31 indicators identified and classified into social, ecological and economical dimension
Calculation of environmental loads by means of a LCA	Specific data regarding manufacturing such as embodied environmental loads intensities for energy and distribution such as embodied environmental loads intensities for transportation
Establishing different lifecycle scenarios	Part and material alternatives
Application of PSD to figure out the balance between technical and sustainable performance	Balance CO_2 emissions and power output of the alternator
...	...

3 Solution Approach

3.1 Knowledge assets

Usually, assets are known as an economic value from the stock market which are owned by an individual (or a corporation) and can be converted into cash. On the other hand, an asset can be defined as a general resource or item of value. That way, knowledge can be described as assets in engineering design. Table 2 provides an overview of different types of knowledge assets.

Table 2 Selection of knowledge assets (classification derived from industry experience)

Product knowledge	Organisational knowledge	Process knowledge	...
Requested specification	Project team members	Assembly collision	...
Feasibility study	Quality Management plan	FMEA results	
Mandatory specification	Memos	Crash test results	
Maintenance cycle	E-Mails	Process procedure	
Material checklists	Minutes	Test instructions	
...	...	...	...

Furthermore, the various items or rather the assets of Table 2 can be structured according to the type of knowledge and the relations between the types and assets. Hence, a whole knowledge structure can be established (Figure 3). IT systems along the product development process have BOM (Bill of Materials) or product structures as a backbone of product information retrieval in common. In general, product structures and characteristics adequately define a product during the development process until a physical product is generated.

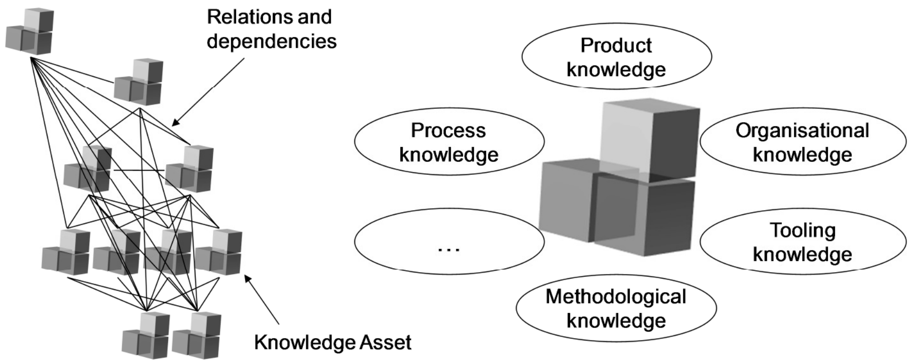

Figure 3 Examples and Structure of Knowledge Assets

Due to the need for a robust bill structuring process today's literature and standards recommend to describe products hierarchical and structure them into successive levels of systems, subsystems, assemblies, subassemblies and components [10]. Within a PDM environment a product structure can be organized efficiently as logical dependencies between different product elements can be established. In doing so, a product's complexity can be handled efficiently along the different IT systems of a product development process. It is thus evident to link knowledge assets with the product structure. That way, knowledge assets can be structured and organized according to the product hierarchy. Users have directly access to items (e.g. CAD part models) and their according knowledge assets (e.g. dimensioning and contact to expert).

3.2 PDM system as a platform for solution integration

PDM is the holistic management of all data from both existing and new products that are generated within the product lifecycle. The use of this data can be controlled by predefined processes. The term "PDM" is often defined in the literature as the product-specific handling of engineering data [11]. The Association of German Engineers (VDI) has defined PDM, in the VDI guideline 2219, as technical databases and communication systems, which consistently store, manage and provide information about products and their development processes respectively lifecycle for relevant areas in the company. Furthermore, most systems offer the ability to navigate through complex product structures and documents, and to provide selected data for further processing. Although the popularity and the usage of the PDM systems increases constantly [12] and the providers offer more and more functions for them, there has not been done much in the field of the knowledge management in PDM systems. Few PDM system providers even list knowledge management as a feature of their product [13], but these are rather functions to manage requirements, development drawings, test results and specifications. For this reason, companies induce themselves to launch additional knowledge management systems. In many cases, these are stand-alone solutions, which are decoupled from the system landscape, the company processes and especially from the "standard" development environment (such as CAx and PDM systems).

3.3 Integration of knowledge assets into a specific PDM system

The PDM system, which we have chosen for our research, is Teamcenter Engineering 2007 (TCE) from Siemens PLM Software. It provides the needed interfaces and tools for further development and customizing. The implementation of knowledge assets into TCE requires the deeper analysis of its system architecture and its data model. The basic architecture of TCE is the four-tier architecture. It consists of client-tier, web-tier, enterprise-tier and resource-tier (Figure 4).

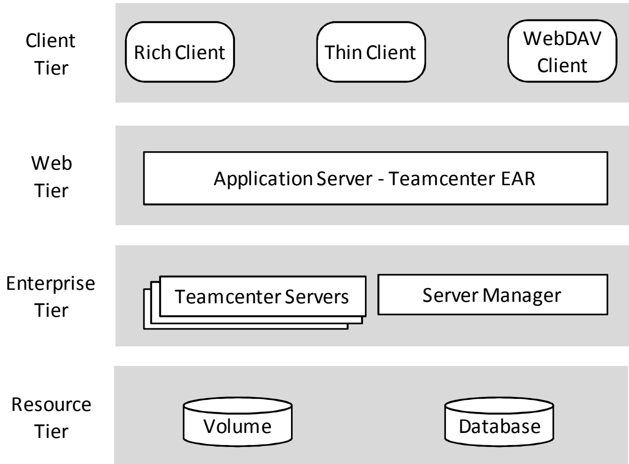

Figure 4 The basic system architecture of Teamcenter Engineering

The client-tier consists of TCE clients that allow the interaction with users. The web-tier is responsible for the communication between the clients and the server services in the enterprise-tier. Moreover, it allows the worldwide cooperation and communication over Internet on one PDM system instance. The enterprise-tier provides the actual functionality. The application logic is designed modular and is organized as server processes in this tier. Additionally, the resources for all active users are also managed in this tier, as well as the database operations such as selecting data from databases or re-writing data in databases. The resource-tier consists of the database server together with the databases, the file server and the file-vault. The data deposited here is divided into product data and metadata. Product data is stored in directories on the hard disc, metadata, on the other hand, is stored in database solutions such as Oracle or MS-SQL. The metadata has the function of describing, classifying, managing and organizing the product data. In this context, the following data is regarded as metadata: Folder, Item, Item revision, Dataset, Form and Item attribute. We classify the knowledge asset as metadata within the TCE-data modeling context due to its specifications. The implementation of knowledge assets requires a modification of the TCE data model. The new business object, which represents knowledge assets, needs to be added into the TCE data model. Business objects are fundamental objects of TCE which are used to model the business data. They represent product parts, documents, change processes, etc. After a throughout analysis we detected that the native form business object, which is a child of the WorkspaceObject, provided by TCE already fulfils many of the requirements of knowledge assets as a business object and therefore can be used as a basis for the knowledge asset business object (Figure 5).

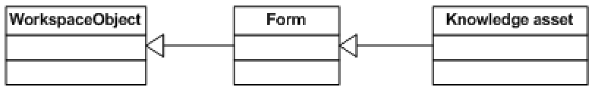

Figure 5 Knowledge asset in the business objects hierarchy

The knowledge asset business object was created using Business Modeler IDE which is recommended by Siemens PLM. After adding new attributes and relations to the new business object the knowledge asset was ready to be used on the client tier. Although the knowledge asset could be used on the client tier immediately, its distinction from other business objects is needed for efficient usage. Therefore, we used the Business Modeler IDE to set a unique icon for the new knowledge asset. The usage and the test of concept were then carried out in a project which is described in the next chapter.

4 Case study

The aim of the project "Urban Mobility" was to develop a low-emission vehicle which can easily distribute goods through urban areas. The whole planning and development activities were supported by TCE. All documentation, including requirements, drawings etc. were entered and managed using TCE. The focus was on the use of knowledge assets during the design phase. During the design process, several conventional and unconventional decisions have to be made. In this situation, is important to provide decision-relevant knowledge. This can now be achieved with knowledge assets.

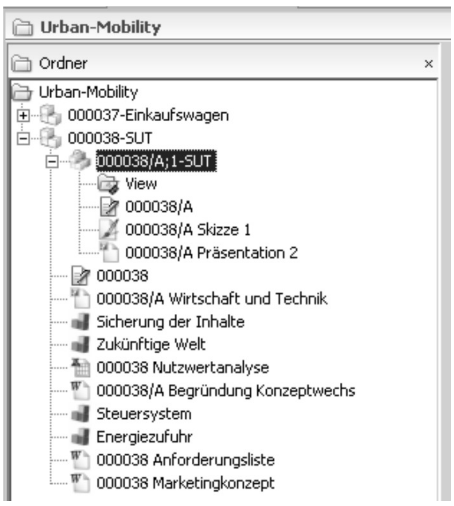

Figure 6: Product/knowledge structure

After the first draft of the project concept, product data was implemented into TCE. At the same time, the project team created knowledge assets according to the different items. The first knowledge assets have been implemented by the engineers classified into the category "Product knowledge – Problem statement" (issue of technical feasibility and safety of the vehicle). Figure 6 shows how knowledge assets are implemented and linked to the product structure. Furthermore, an outlook of knowledge assets is provided by the example of “Material Aramide” (Figure 7). The implemented knowledge assets made the whole team aware of problems which can occur, e.g. in the field of sustainability feasibility. In particular, the problem regarding the LCA of the vehicle was a big challenge. Knowledge assets for technical properties and (manufacturing) process alternatives were created for each part. That way, different LCA approaches could be carried out more efficiently because all information needed was well structured and available. Eventually, the final sustainable prototype was quickly reached by the help of context-sensitive knowledge sharing.

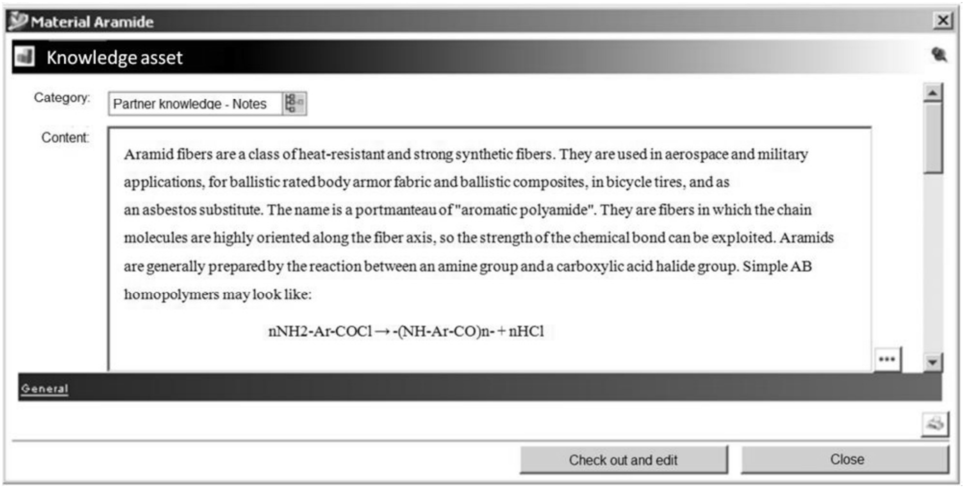

Figure 7: Example of the knowledge asset “Material Aramide”

5 Conclusion and outlook

This paper describes an approach on how (sustainable) product and process knowledge can be organized and provided efficiently for the user in order to improve product development processes. The basic idea is to depose knowledge into knowledge assets which are assigned to the product structure. The solution approach is implemented into a Product Data Management (PDM) environment. A case study has shown that the approach has been implemented successfully in a practical project. Knowledge assets have been applied in order to share design, process and project knowledge between the different project partners. That way, the approach’s benefits have been demonstrated. On the other hand, there are still huge gaps modern knowledge management in engineering has to face. Related to our project we identified three main research fields which we plan to investigate further:

1. Implementation of relations between different knowledge assets to set up a knowledge structure. At this time, knowledge assets have to be assigned to each item of the product structure manually. There is no logic connection between the assets.
2. The knowledge assets and their content have to be standardized in order to work more efficient and more comfortable with the knowledge structure.
3. Definition and implementation of metrics between sustainable knowledge assets and their interaction with traditional design parameters (e.g. costs and quality)

Finally, for efficient application customization of PDM environments is necessary and time consuming. Aside from research, a next step should be testing of knowledge assets in real industrial development projects.

Acknowledgments

We express our sincere thanks to the German Research Foundation (DFG) funding this project partly. The authors wish to acknowledge important professional contributions from Masato Inoue as well. Finally, we thank all readers and hope that we provided interesting and useful material.

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The "Sustainable Building - Accelerator’’

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Abstract: To achieve the high ambitions which are set for the built environment, such as the realization of an energy-neutral built environment in 2050, big changes are required rapidly. Therefore innovations in the built environment have to be accelerated. To assist clients in achieving this acceleration Royal Haskoning introduces the ‘’Sustainable Building - Accelerator". This article describes the concept and the added value of the "Sustainable Building - Accelerator".

Keyword : Sustainable Buildings, Lifecycle costs, Scenario’s, Road mapping

1 INTRODUCTION

The "Sustainable Building - Accelerator” evolved from the vision that was presented on January 13th, 2010 at the Technical Council TVVL symposium [1]. Now the first version of the ’’Sustainable Building - Accelerator’’ has been developed. This first version can be used to compare the performances of different building designs over a longer period of time. The performances include Lifecycle costs.

Many people in the Netherlands and worldwide call out, that it is necessary to accelerate innovations in the built environment, to achieve the high ambitions on sustainability in time.

The ’’Sustainable Building - Accelerator’’ originated form the assumptions that the required acceleration of innovations within the built environment is not yet achieved due to:

- the small amount of innovative solutions which are generated by design teams, because (i) the design process is characterized by mono-disciplinary sequential steps and (ii) the design is most of the time constructed from partial existing solutions.
- the application of innovative design solutions is not considered adequately (not often, not all the pros and cons are considered) and not considered over the lifetime of the building, see Figure 1. This is because: (i) the pros and cons over

the lifetime of the building are not within a contract of one single party, or are not clearly linked to parties, (ii) there is no clear method prescribed and (iii) there is no adequate tool available.

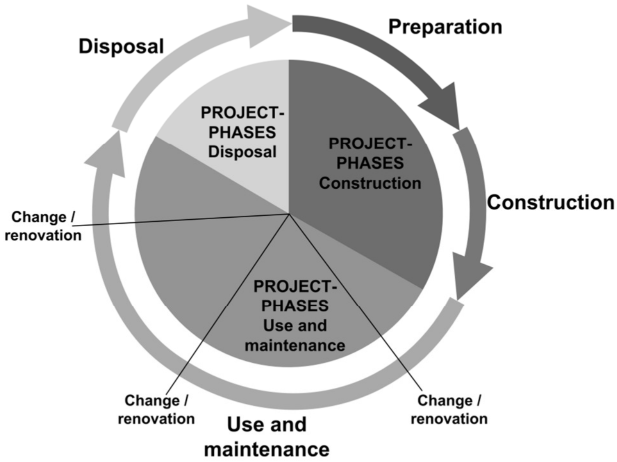


Figure 1 Representation of the life cycle costs compared to the cost of construction and the different costs of which the life cycle costs consist.

2 The ''Sustainable Building - Accelerator''

To innovate and accelerate, in addition to develop innovative products and systems, also a new way of working and designing is necessary. This will lead to a demand driven innovations which will accelerate the realization of a sustainable built environment. The "Sustainable Building - Accelerator'' supports a new way of working, designing and making design decisions.

Innovations and the application of sustainable solutions in buildings are stimulated and realized with the "Sustainable Building - Accelerator'' by using a structured and systematic approach during the design phase of the building. Therefore a design methodology and a tool is developed, to support the design team during the early stages of the design with:

- the generation of innovative sustainable building design solutions;
- the selection of innovative sustainable building design solutions (including adjustments and changes over time) considering a longer period.

2.1 Generation of innovative building design solutions

The research focus of the part "generation of concepts" of the "Sustainable Building - Accelerator" was formulated in collaboration with Prof. W. Zeiler of the Eindhoven University of Technology with reference to previous research in this area [2]. The argument here is that designers in the early stages of the design of an ambitious and innovative project need methodological support. Where it is assumed that the designers are experienced and work on a knowledge-intensive level.

Important aspects in the required design methodology are:

- the organization of the design team (roles and tasks),
- the design process (workshops, etc. to enhance the solution space and find a solution by diverging and converging)
- the method used to design,
- the applied design tools,
- the communication, within the design team, in different design stages of the design process.

2.2 Selection of sustainable building design solutions – LCC part of the ''Sustainable Building – Accelerator'

Design decisions are increasingly made by developers and a growing number of consortia with an integrated contract (e.g. DBFMO: Design, Built, Finance, Maintain and Operate), based on a Life Cycle Cost and Life Cycle Performance considerations. The total costs, performances and variations in the use of housing (including building services), are taken into account over a longer period. This is to achieve optimum solutions, where:

- the added value of the building for the user and his environment (the environment) is as large as possible;
- a financial benefit achieved in a market where energy prices rapidly rise, the prices of innovative (e.g. energy saving) products quickly reduce and the flow of new innovative products accelerates;
- in the design innovative solutions are applied and in for the future the application of innovative solutions (adaptation) and changes in the use of the building (flexibility) is taken into account.

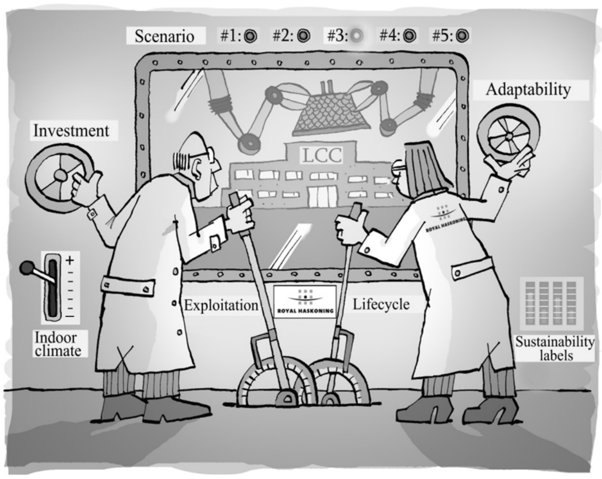


Figure 2 Schematic representation of part of ''Sustainable Building – Accelerator'': method and tool to quantify design decisions on life. [Illustration of Floris Oudshoorn - stripstudio.nl]

This is different from the traditional way of making design and housing decisions. Traditionally, these decisions are taken by a static approach that includes only the initial investment and simple pay out times (SPOT). Using this traditional approach large profit will be missed, see [3], and there is no anticipation to dynamic aspects: (a) the needs within integrated contracts to maximize resale value and minimizing operating costs, (b) the rapid changes in the market and (c) the possibilities for adaptation of new techniques.

The LCC part of the ''Sustainable Building – Accelerator'' provides a clear, useful and reliable method and tool, which can be used to make design and housing decisions based on a lifecycle approach, see Figure 2. The ''Sustainable Building – Accelerator'' is widely applicable and can be used for new and existing buildings.

3 The ''Sustainable Building - Accelerator'': LCC PART

The first version of the LCC method and tool is developed and presented in this article. The requirements for the development of this method and tool version were:

- Broadly applicable dynamic financial accounting tool where changes over the lifespan (including replacement and improvement investments, energy costs, other operating costs) are clearly specified for four design variants.
- Strong presentation / communication tool that gives insight and a good overview using indicators (per m2) and a graphically display of the results of the design variants, see Figure 2,
- Insight in the sensitivity of the results for variations in the different input parameters.
- Applicable to carry out a LCC-study fulfilling the requirements of BREEAM-NL (BRE Environmental Assessment Method for the Netherlands) credit MAN 12 [4]. If the requirements defined in credit MAN 12 are fulfilled a maximum of 2 points within the assessment method can be scored.
- Applicable from the start until the end of the design stage. Required input data (values per m^2) can easily be corrected during the design and when more detailed information is available.

Near future developments:

- Making clear the benefits: such as savings in labor costs by reducing absenteeism and/or higher productivity due to a better indoor climate. The LCC approach is thus extended to a LCP (Life Cycle Performance) approach.
- The development of knowledge and the gathering of information to determine the indicators/input to be entered for each relevant design decision to be made.

The available version of the LCC is now a strong communicative and versatile financial calculator. Changes over time can be discounted. The required input depends on the specific design question and should be determined before the ''Sustainable Building - Accelerator'' can be used.

4 EXAMPLE - ENERGY STUDY

To illustrate how the LCC method and tool works, it is applied to an energy study. This study, for the project Cromstrijen TNO Defence laboratory, has been conducted by Royal Haskoning [5]. The energy study was performed using a traditional static approach and LCC was not applied. To illustrate the added value of the "Sustainable Building - Accelerator'' it was applied to four different energy generation systems:

- HR+CKM: Boilers and Compression Cooling Machine;
- WKO+HP: Long Term Energy Storage in the Soil (acquifer) and Heat Pump;
- WKK: Cogeneration of Heat and Electricity using Gas (CHP-gas) and Absorption Cooling;
- WKK (bio): Cogeneration of Heat and Electricity using Deep-frying Oil (CHP-bio) and Absorption Cooling.

Examined were:

- how the outcomes / design decisions change using the LCC assessment;
- how sensitive the outcomes of the LCC assessment are for variations in different parameters.

The results of the energy study [5] performed in the past are presented in Table 1.

Table 1 Results of the energy study [5] using a traditional static approach.

Parameters / variation		HR+CKM	WKO+HP	WKK	WKK (bio)
CAPEX	[€/m²]	37,7	60,0	81,6	89,0
energy	[€/(m²*yr)]	14,7	10,5	6,2	4,0
Fraction elect.	[%]	13%	24%	4%	7%
Fraction gas	[%]	87%	76%	96%	0%
Fraction other	[%]	0%	0%	0%	93%
OPEX	[€/(m²*yr)]	1,79	1,61	4,65	5,04
end value	[€/m²]	-20	-30	-40	-40
CO_2	[kg/(m²*yr)]	53	38	11	7
SPOT	[yr]	-	5,1	7,8	6,9

Legend to Table 1:

- CAPEX (Capital Expenditure): Investments. In the static approach these are only the initial investments. In the dynamic approach the CAPEX also includes replacement and improvement investments.
- Energy: Energy costs are taken into account separately and are divided in the categories gas electricity and other.
- OPEX (Operational Expenditure): Operational costs (here excluding the energy costs), e.g. maintenance, operational management and cleaning costs.
- End value: This is the value of the project at the end of the considered period.
- SPOT (Simple Pay Out Time): This is the resulting simple pay out time using the static approach. Only the initial investment costs and the estimated cost savings on Energy and OPEX after one year are considered.

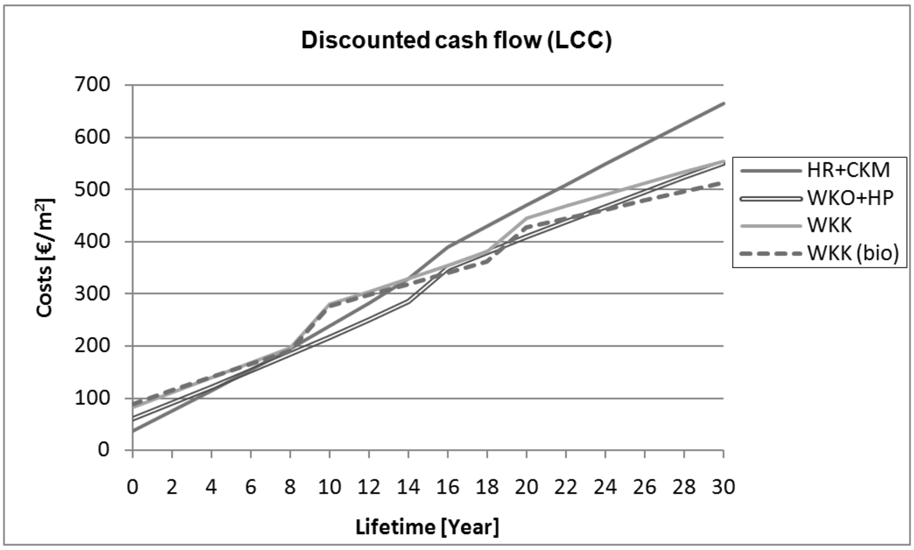
For the LCC calculation additional data is required to calculate the real, discounted and non-discounted cash flows, see Table 2. These cash flows should also be calculated to fulfill the requirements of BREEAM-NL (BRE Environmental Assessment Method for the Netherlands) credit MAN 12, see [4]. The LCC calculation is performed according to the available standards, see [6]. The capital of the investor is also taken into account in the calculation separately, see "equity" in Table 2.

Table 2 Input parameters for LCC calculation (discounted cash flows).

General parameters			
period	n	30	[yr]
electricity price increase	j_e	7%	[%]
gas price increase	j_g	7%	[%]
increase bio oil	j_o	9%	[%]
inflation	j	2,5%	[%]
equity		20	[€/m²]
internal discount rate	R_e	7%	[%]
external discount rate	R_d	6%	[%]
repayment period	n'	30	[yr]
financing interest		6%	[%]

Additionally, scenarios are specified for each variant. Scenarios are specified over a period (here: 30 years in compliance with BREEAM-NL MAN 12). A scenario consists of investments (replacement & improvements, see CAPEX), energy demand (see Energy) and other operating costs excluding energy (see OPEX) over time. In the calculation the following aspects are included:

- replacement investments are included in the scenarios for each variant;
- supply of energy varies over the specified period. The specified values are based on experience. The values indicate that after construction, the energy performance will be lower than expected and each year further it will deteriorate. After renovation, the energy performance will be better than after construction and each year further it will deteriorate again.
- operating costs excluding energy are assumed to be constant over time.



	HR+CKM	WKO+HP	WKK	WKK (bio)
LCC; costing	100%	83%	83%	77%

Figure 4a LCC results – (accumulated) discounted cash flows for each scenario.

The results of the calculations are presented in Figure 4. In comparison to the energy study [5] (static approach) the results of the LCC calculation (dynamic approach) show that:

- The payback period (intersection of line with the accumulated costs (cash flow) of the corresponding variant with the reference) differ from the static approach;

The order of most profitable variants is changed. Application of BIO-Cogeneration of Heat and Power (BIO-CHP) is more profitable than Long Term Energy Storage (LTES = WKO) in the soil in combination with a Heat Pump (HP).

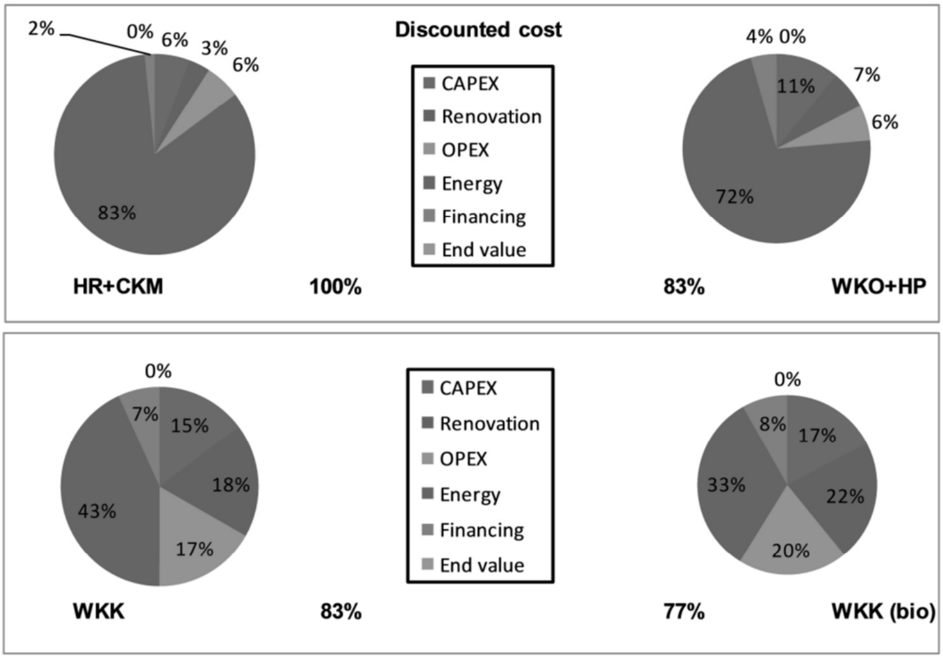


Figure 4b LCC results – Breakdown of LCC costs after 30 years for each scenario.

Furthermore, the results of the LCC calculation show that:

- The breakdown of costs is different for each variant;
- The energy costs are by far the largest costs. Investing in energy saving measures will therefore be profitable;
- Other operating costs excluding the energy costs are low for the reference system and thermal energy storage system (LTES=WKO), but are relatively high for the cogeneration systems (CHP).

The LCC-tool can also automatically determine the sensitivities of the calculated results for variations in input parameters. The sensitivity of the results for the reference system is determined for the variation of different parameters, with values each within a given bandwidth. The considered parameters and bandwidths are presented in Table 3.

Table 3 Parameters including bandwidths used to determine the sensitivity of the LCC calculation results.

Estimating variables	Base estimate X_m	Range X_a, X_b	Cost outcome based on range C_a, C_b
Internal discount rate	7%	6% to 8%	703 to 609
External discount rate	6%	5% to 7%	686 to 623
Inflation	2,5%	-0,5% to 6,7%	637 to 689
Electricity price increase	7%	6% to 9%	650 to 661
Gas price increase	7%	6% to 9%	631 to 702
Increase price (other)	9%	6% to 12%	653 to 653
CAPEX	38	30 to 45	612 to 685
Energy	15	12 to 18	551 to 778
OPEX	1,79	1 to 2	631 to 638

The calculated sensitivity and coefficience of variance for the reference system are shown in Figure 5.

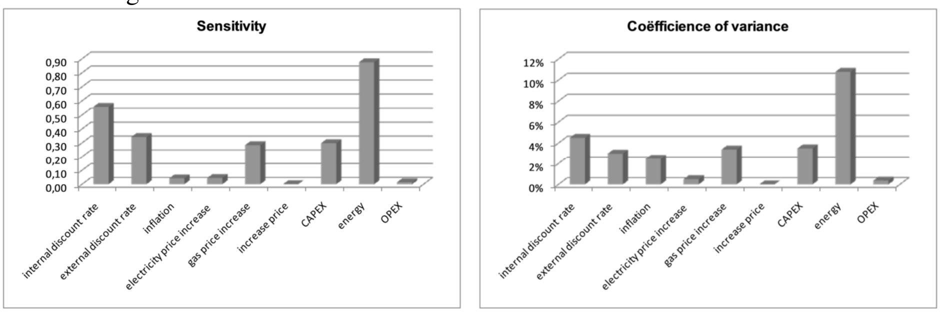


Figure 5 Calculated sensitivity and coefficience of variance for the reference system.

The results of sensitivity calculation show that the LCC results are most sensitive to the energy price increase and the discount rate (internal, external). Since the costs and the breakdown in costs differ for each variant, also the sensitivity for each parameter is different for each variant. Also the scenarios can differ for each variant, e.g. replacements and/or changes are realized in a different years. In order to manage and control future cash flows these sensitivities can already be considered within the design stage of the building.

5 CONCLUSION

The "Sustainable Building - Accelerator'' is a method and a tool that supports the design team in the early stages of the design by using a dynamic instead of a traditional static approach. The dynamic approach consists of a LCC calculation based on discounted cash flows and the use of scenario's. The static approach uses only a calculation of the simple pay out time for different variants and no changes and/or modifications over the life time are considered.

The "Sustainable Building - Accelerator'' supports design teams and therefore accelerates sustainable innovations in the built environment using a demand driven approach. The LCC component compares the performance of different scenario's. This enables the consideration of adjustments to enhance the performance of the building in the future.

Royal Haskoning has developed the LCC part of the "Sustainable Building - Accelerator''. This allows energy studies, which are not based on a LCC approach, to be extended with a LCC calculation and to extend the variants with scenario's (considering changes and modifications over a longer period). Road mapping, modifications to achieve a better performance, is supported. The LCC method can be used to perform the calculations required by BREEAM-NL credit MAN 12. In general the developed LCC tool is widely applicable and has a strong and insightful presentation of the input and the results. This is shown with an example in this article.

6 FUTURE DEVELOPMENT

In 2010 Royal Haskoning formulated a research and development proposal in collaboration with Eindhoven University of Technology, SBR and the Dutch Green Building Council to develop the "Sustainable Building - Accelerator''. To perform research and development for the full scope of the proposal funding is still required.

Nevertheless Royal Haskoning has already started the development of the "Sustainable Building - Accelerator'' as their own product and service. The priority in the near future is now providing insight into: (a) the benefits (e.g. lower labor costs through lower absenteeism and higher productivity due to improved indoor thermal climate and air quality), (b) variations in flexibility (functional changes, shrinkage, expansion) and (c) adaptability (new techniques) for each variant/scenario.

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Sustainable Industrial Systems: A Case Study from the Malaysian Palm Oil Industry

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Abstract: Regulatory drivers such as the EU's Sustainable Procurement Directive are creating a need for sustainable products where suppliers must provide evidence of the environmental impact of the products they deliver to customers. The environmental impact of the products is closely connected to the environmental performance of the supply networks that transform the product from raw materials and deliver it to customers. In this paper we argue that lifecycle management approaches can usefully be applied to such supply networks to support the design of sustainable industrial systems. Using the Malaysian palm oil industry as a case study, the paper focuses on the definition of a case study supply network with a view to creating information needed to support lifecycle assessments of its operation under alternative environmental management systems. Early results from studies exploring the influence of the ISO 14001-based environment management systems on the operation of Malaysian palm oil industry supply network are presented.

Keywords: Systems engineering, strategic management, environmental management system, ISO 14001, sustainability

1 Introduction

In order to achieve improved standards of sustainability, there is a need for the Malaysian palm oil industry to develop sustainability indicators to pursue certification of sustainably produced palm oil with full traceability. As demand for low cost and high quality vegetable oil increases, to feed the world's growing population, frameworks to support the visualisation of sustainability of palm oil supply networks will contribute to improving the sustainability of palm oil production.

The need to produce palm oil sustainably has led to the establishment of the Round Table on Sustainable Palm Oil. This acts as a platform to reach mutual understanding at an international level among a range of palm oil stakeholders, including; palm oil growers, palm oil processors/traders, consumer goods manufacturers, retailers, investment organisations, social and development non-governmental organisations and environmental or nature conservation non-governmental organisations. Such understanding could be translated into common actions towards improving the sustainability of palm oil production and used in its entire supply chain. The Round table on Sustainable Palm Oil has progressed by formulating a set of principles and criteria for sustainable production, but has yet to implement a scheme to enable sustainably produced palm oil to be certified with full traceability.

Roundtable on Sustainable Palm Oil Principles and Criteria	**ISO 14001**
Principle 1 – Commitment to transparency	The RSPO requirements for this principle are consistent with the ISO 14001 communication sub-element, with the exception that ISO 14001 does not specifically mention the reporting of information on social issues.
Principle 2 – Compliance with applicable laws and regulations	This is a mandatory requirement of ISO 14001 that is checked by internal and external auditors. It is important to note that ISO states that appropriate information about legal and other requirements should be communicated to all persons working for or on behalf of the organisation.
Principle 3 – Commitment to long-term economic and financial viability	This commitment is additional to the requirements of the ISO 14001 standard.
Principle 4 – Use of appropriate best practices by growers and millers	The ISO 14001 guideline does not specifically refer to “best practices”.
Principle 5 – Environmental responsibility and conservation of natural resources and biodiversity	The ISO 14001 standard requires the preparation of management plans and environmental improvement plans for reducing the negative environmental impacts associated with the significant issues.
Principle 6 – Responsible consideration of employees and individuals and communities affected by growers and mills	An additional to those of the ISO 14001 management system specification.
Principle 7 Responsible development of new plantings	The ISO 14001 standard requires any changes to – the scope of the company’s activities to be included in the environmental management systems.
Principle 8 – Commitment to continuous improvement in key areas of activity	Continuous improvement is one of the doctrines of ISO 14001 and the company must commit to this process in order to achieve certification.

Table 1: Links between the Roundtable on Sustainable Palm Oil principles and criteria and ISO 14001 elements

In this research, potential influences of ISO 14001-based environment management systems on the operation of Malaysian palm oil industry supply networks are explored. ISO 14001 is an internationally recognised standard for environmental management systems and provides the requirements according to the standards outlined. Environmental management system implementation requires that companies obtain ISO 14001 certification. The Roundtable on Sustainable Palm Oil principles and criteria provide an interpretation of the sustainable palm oil requirements for incorporation within the ISO 14001-based environment management systems framework. The implementation of an environmental management system as a tool in this study can be regarded as a response to the requirements of the Roundtable on Sustainable Palm Oil principles and criteria (as shown in Table 1) in realising the design of sustainable industrial systems. To date, 20 mills in Malaysia have obtained Roundtable Sustainable Palm Oil certification. [1] However, the authors argue that standard operating procedures need to be modified not only to incorporate the requirements of specific Roundtable on Sustainable Palm Oil principles and criteria but also for the realisation of more sustainable industrial systems.

Market pressures coupled with regulatory drivers such as the EU's Sustainable Procurement Directive are demanding sustainable products where suppliers are required to provide evidence regarding the environmental performance of the industrial systems that produce the products along with the products themselves. In response, ISO 14001-based environmental management systems provide a means of tracking, managing and improving performance regarding to these environmental requirements. The influence of ISO 14001 on the implementing organisation performance plays a new way of thinking of a balance economic, societal and environmental growth for sustainability. ISO 14001 certification has a positive impact on both economic and environmental performance (Ann, et.al, 2006). In the future, the implementation of an environmental management system framework model, through registration with ISO 14001, could become the norm.

2 Structure of the Paper

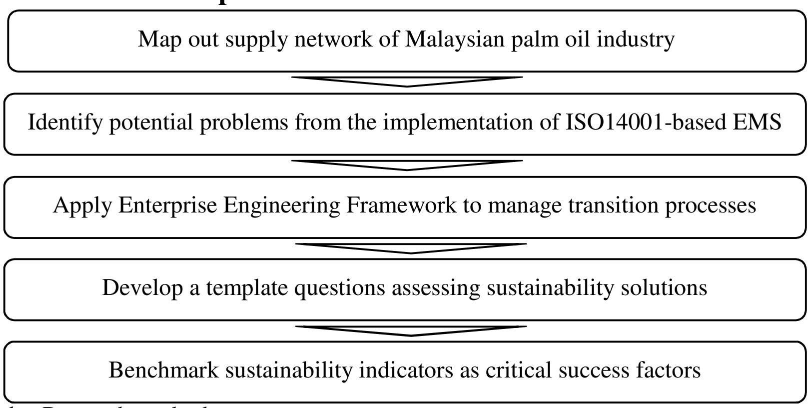

Figure 1: Research method

An overview of the regulatory framework within which the Malaysian palm oil industry sits is given in Section 3. This is followed by a literature review, in Section 4, which collects together information on Malaysian palm oil industry supply networks. The research method used in this research is shown in Figure 1. It can be seen that the research is based on a definition of a supply network of the Malaysian palm oil industry; this was used to identify potential problems for the implementation of ISO 14001-based environmental management system in the case study network and is provided in Section 5.1. The supply network map was used to identify potential problems from the implementation of ISO 14001-based environmental management systems; these are reported in Section 5.2. Step 3 involved the application of the so-called "Enterprise Engineering Framework" (McKay, A et. al, 2009). This framework brings together ideas from systems engineering and strategic management and supports their application to the design of enterprise networks. The framework was used to develop sustainability

[1] Fourth ASEAN State of the Environment Report 2009. Available at: http://www.aseansec.org/publications/SoER4-Report.pdf

questions as uncertainties affecting the implementation of the design of sustainable industry system in the Malaysian palm oil industry. The template questions can establish relationship between the Malaysian palm oil industry as an organisation collaborating with its supply networks that are responsible for the process of managing the sustainability of the palm oil it produces. From the delivery of these sustainable solutions, the benchmarked sustainability indicators can be used as critical success factors for the redesign of materials flow, new technology advances for recycling, and environmental and socio-economic impacts assessments in the future.

3 An overview of the regulatory environment Malaysian palm oil

In Malaysia, ISO 14001 certification is carried out by Standards and Industrial Research Institute of Malaysia (SIRIM), QAS International Sdn. Bhd. At present, the evaluation of the effectiveness of the ISO 14001-based environmental management system in reducing environmental pollution is difficult to make. Nevertheless, the evaluation is only based on the number of companies certified to ISO 14001. The high number of companies awarded the certificate indicate high level of environmental awareness among the industrial sector. As up to November 2010, a total of 56 companies have been certified with ISO 14001 by Standards and Industrial Research Institute of Malaysia (SIRIM), QAS International Sdn. Bhd., Malaysia as an approved Roundtable on Sustainable Palm Oil (RSPO) supply chain certification body. [2]

4 Literature review

The Malaysian palm oil industry is a highly regulated industry. Being sensitive and proactive on current environmental concerns, the Malaysian palm oil industry is actively pursuing international series of standards notably on climate change, life cycle assessment, eco-labelling, environmental communications, and environmental management systems. Although the ISO 14001-based environmental management systems model was intended to foster continual environmental improvement, the standard does not establish absolute requirements for environmental performance, other than a commitment to compliance with applicable regulations, nor is environmental performance a factor in certification. ISO 14001 provides a framework for organisations to implement their environmental policies and third party verification that they are doing so. As a management system standard it allows more flexibility in the practices applied and the speed of implementation. ISO 14001does not provide verification that specific performance requirements have been applied, unless linked to a code of practice which defines the performance requirements. In addition, it does not permit product labelling.

Table 2 showed a matrix of environmental management systems implementation which can be related to the supply network map from the summary of literature review. From the matrix shown, the researchers agreed that the successful implementation of environmental management system were due to the on-going commitment and support from the top management and better environmental improvement. For instant, Zutshi, *et al.* (2004) examined the role of employees and suppliers as organisational stakeholders during the ISO 14001-based environmental management systems adoption process. Some empirical findings indicated that the adoption was influenced by organisation cultures (GE Ann *et al.*, 2006), regulatory and customer pressures (TK ElTayeb *et al.*, 2010), and reducing ecological impacts of economic activities (D Walker *et al.*, 2007). It was also a systematic approach to manage environmental issues in identifying opportunities of

[2] Standards and Industrial Research Institute of Malaysia (SIRIM), QAS International Sdn. Bhd., Malaysia.

conserving material and energy consumptions, reducing emission and waste, thus improving process efficiency (B. Poksinska *et al.*, 2003). While other results indicated that involvement of all employees and flow of information factors influence the efficiency and effectiveness of environmental management system implementation (L Lawrence *et al.*, 2002).

	Top management support	Documentation & Control	Material Consumptions	Biodiversity & Ecological Impacts	Energy & Water Usage	Emission & Wastes
Authors	**Environmental Management Systems**					
A Zutshi, AS Sohal. (2004)	✓	✓	✓	✓		✓
B Poksinska, JJ Dahlgaard, JAE Eklund. (2003)	✓	✓	✓		✓	✓
D Walker, M Pitt, UJ Thakur. (2007)				✓		✓
GE Ann, S Zailani, NA Wahid. (2006)	✓	✓		✓		✓
L Lawrence, D Andrews, B Ralph, C France. (2002)	✓	✓				✓
MA Balzarova, P Castka, CJ Bamber. (2006)	✓					✓
N Johnstone, J Labonne. (2009)	✓	✓		✓		✓
Sebhatu SP, and Enquist B. (2007)	✓	✓				✓
TK ElTayeb, S Zailani, K Jayaraman. (2010)		✓				✓

Table 2: Matrix of Environmental Management System Implementation

Strengths	**Weaknesses**
1. Defines a company's environmental philosophy	Ambiguous definitions and general vagueness of terms (environmental aspect, environmental impact, continual improvement, etc.)
2. Identifies environmental impacts and aspects	Lack of substantial public environmental reporting and public communication requirements
3. Sets regular objectives and targets for managing environmental impacts	Inconsistent global applications and interpretations of the standard
4. Creates a thorough employee training programme	Lack of clarity about the ISO 14001-based environmental management system auditing criteria
5. Provides documentation/record	No requirements for tracking the financial guidelines success or failure of an ISO 14001-based environmental management system (via environmental cost accounting, cost benefit analysis, etc.)
6. Ensures top management commitment and involvement as well as system improvements	No guidelines for standard environmental performance indicators, which consequently makes the comparison of certified firms' environmental performance virtually impossible.

Table 3: Strengths and Weaknesses of ISO 14001-based environmental management system

Sustainability can be achieved through optimisation of the use of resources along the product lifecycle, while maintaining quality of products and services (Ciceri *et al.*, 2009). However, optimization and quality of product related processes are strongly based on the flow of information. The context of information and knowledge sharing between producers and consumers is important for delivering service and sustainability along the product lifecycle. There is also a need of addressing topics such as interoperability throughout the supply network, knowledge sharing in the product chain and social implications of sustainability. For this reason, product lifecycle management represents a very important approach for achieving a more sustainable paradigm of in the design of sustainable industrial systems.

There were both strengths and weaknesses to ISO 14001-based environmental management systems in heightening organisation awareness of the importance of managing environmental impacts and actions as shown in Table 3.

5 Case study results

5.1 Map of an example Malaysian Palm Oil Industry supply network

A map of the Malaysian Palm Oil industry supply network is given in Figure 2. The boundary of the system considered in this research is shown by the dashed box; these are the parts of the supply system that are located in Malaysia. The information about customers is included in the map because they influence the requirements for sustainability-related information. For example, the regulatory framework under which food producers operate differs both across national boundaries and with the regulations that, for example, cosmetic and detergent producers must comply with.

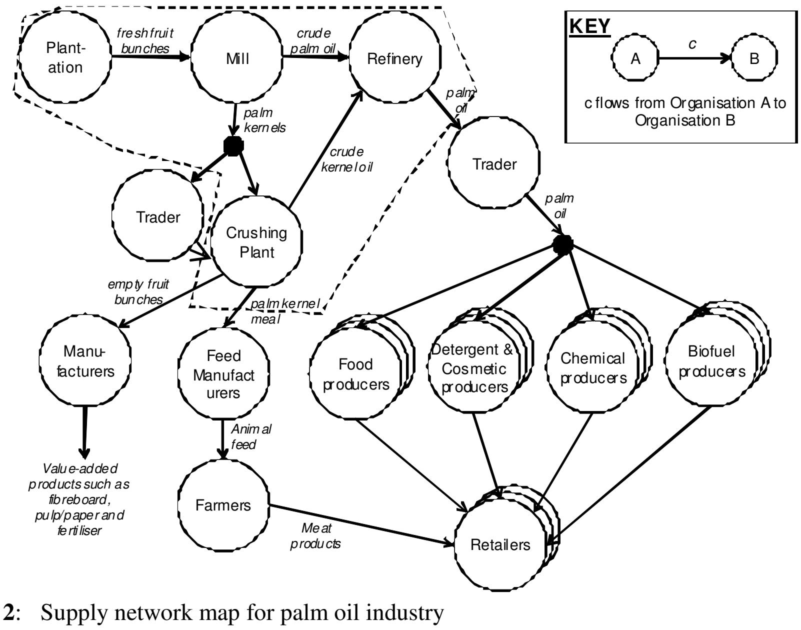

Figure 2: Supply network map for palm oil industry

The focus of mapping out the supply network for Malaysian palm oil was to review the implementation of ISO 14001-based environmental management systems from cradle-to-gate of the supply network. The system served as a boundary to identify, predict and communicate information about the impacts on environment. The boundary covers from plantation – mill – refinery – crushing plant (dashed box). From the production processes side, the implementation of ISO 14001-based environmental management systems should be enhanced with proper procedures so that the entire production process becomes more environmentally friendly.

However, sustainability solutions should include issues and flows that extend beyond the nodes up to the retailers of end of life. In order to do so, the Malaysian palm oil industry and its research and development arm are continuously working to improve the industry's environmental performance. Various approaches and technologies aimed to reduce the impact of the industry on the environment have been converted to successful practices in palm oil plantation, palm oil mill, and refineries. The industry envisions achieving the highest standards of sustainability of palm oil.

5.2 Potential Problems from the Implementation of ISO 14001-based Environmental Management System Model in the Malaysian Palm Oil Industry

Environmental management systems have potentially complementary and significant implications for an organisation's environmental sustainability of defining and establishing sustainability among supply networks (refer to Figure 2). However, when environmental management systems are adopted without consideration of a whole sustainable industrial system, environmental benefits are likely to diminish. This is because the organisation supply networks partners are unlikely share its environmental goals and environmental sustainability of any organisation is inevitably limited by if sustainability related questions are not incorporated in the design of its supply network.

From the supply network mapped out in Figure 2, the boundary of the system considered in this research can be seen to range from the plantation (raw materials) to retailers (end of life); as such the research relates to the management of a large portion of the palm oil cycle. ISO 14001certification is applied to organisation rather than the products of that organisation (within the dashed box in Figure 2). In this case, product labelling (beyond the dashed box in Figure 2) was not permitted. In the absence of product labelling, chain of custody is not normally traced. The implementation of ISO 14001-based environmental management systems help to reduce the costs of regulation, in terms of government enforcement effort and the costs of compliance of the individual enterprise. Hence, ISO 14001 certification can be used to replace some statutory reporting requirements and was not a substitute for a regulatory framework, but the monitoring and reporting systems of a well-managed enterprise might substitute for some of the statutory inspections, audits, and reports normally required under government regulations. There was also considerable evidence that an informed public has a strong influence on the environmental performance of industrial enterprises, through a variety of mechanisms that include market forces, social pressures, and support for improved regulatory controls. Hence, it is argued that issues related to product life cycle management such as costs of regulation, product labelling, documentation in proving compliancy, and product information should be taken into considerations when designing a supply network where product sustainability is a key factor.

5.3 Application of Enterprise Engineering Framework for Design of Sustainable Industrial Systems

The implementation of product lifecycle management helps to regroup organisational structure, operation process and resource configuration as facing customers and markets. In this case, the enterprise engineering framework can be used to develop template questions on sustainability issues that build upon the view of an entire product lifecycle. Building better understanding of sustainability related questions is an important in the delivery of sustainable palm oil products. Applying the enterprise engineering framework to the design of a Malaysian palm oil supply network can facilitate the translation of environmental related requirements towards achieving sustainability solutions.

	Define	**Develop**	**Deploy**
Purpose	Explore and define sustainability issues		
Agency	Sustainable industrial products supply network	**Environmental Management Systems**	
Products & services	Sustainability oriented products & services		Design of sustainable industrial system solutions

Figure 3: Enterprise Engineering Framework for Design of Sustainable Industrial systems

Under the enterprise engineering framework, ISO 14001-based environmental management systems can respond as strategic management approach that helps to define how an organisation will address its impact on the environment. The ISO 14001-based environmental management systems can be an agency in the enterprise engineering framework in establishing an environmental policy; undergoing internal assessments of the organization's environmental impacts; creating quantifiable goals to reduce environmental impacts, providing resources and training workers; checking implementation progress through systematic auditing to ensure that goals are being achieved; correcting deviations from goal attainment; and undergoing management review. By doing so, organisations can embed environmental practices deep within their operational systems so that protecting the environment becomes an integral element of their overall business strategy.

In Figure 3, the ISO14001-based environmental management systems sit in the Agency row and served as the intended organisation that applies developed framework or tools to serve the purpose to define sustainability issues in order to deliver sustainable products and services. By applying the ISO 14001-based environmental management systems as an enterprise operating system will mobilise the enterprise capabilities to deliver value to stakeholders through assessing sustainability solutions (from the plantation to retailers in Figure 2). The palm oil products, which sits in the Products and Services row of the enterprise engineering framework, comprises a physical product and associated services that support the product life through the supply networks. During the enterprise realisation process, the design of sustainable industrial systems requirements can be translated to deliver sustainability solutions. Hence, it is argued that the success of sustainable industrial systems is determined by the ability to monitor and verify the implementation of an organisation's quality and environmental policy within the supply networks. It is important that this framework can be adapted to develop template questions to assess sustainability solutions for strategic management that integrates environment, economy and social aspects.

5.4 Developing Template Questions to assess Sustainability Solutions by using the Enterprise Engineering Framework

Applying the enterprise engineering framework to the design of sustainable industrial systems is presented in the format of Template Questions in Table 4. The Purpose row of the enterprise engineering framework defined sustainability issues to answer the triple bottom line implications and supply network influence to the entire supply network (from the plantation to retailers in Figure 2). As for the Agency row, the organization in-charge of the Malaysian palm oil industry sits to provide sustainable solutions by implementing tool such as the environmental management system to establish relationship between the sustainability questions and parameters by developing sustainability indicators to benchmark critical success factors. Once the sustainable indicators were identified, the Products and Services row of the enterprise engineering framework can then define sustainability oriented products and services by answering to the needs and desires for successful attributes in designing of sustainable industrial systems.

Level Aspects for an enterprise	Template questions assessing sustainability solutions
1. **Purpose** -defining sustainability issues	*What are the triple bottom line implications and the best possible sustainable solutions?* *How can the sustainable supply network influence the entire supply chain?*
2. **Agency** -defining sustainable industrial products supply network	*Which organisation is in charged in providing sustainable solutions?* *How can the implementations of Environmental Management System by the related agencies influence the sustainable supply network?* *What are the critical success factors to benchmark sustainable indicators?*
3. **Products and Services** -defining sustainability oriented products and services	*What are the need and desire for sustainable attributes in products & services?* *How can the sustainability oriented products and services be developed?* *Can the design of sustainable industrial systems solve sustainability issues?*

Table 4: Template questions for assessing sustainable industrial systems using the Enterprise Engineering Framework

5.5 Benchmarking sustainability indicators as critical success factors

By assessing sustainable industrial systems through answering the template questions provided, the authors anticipate to benchmark sustainability indicators of the mapped out supply network performance (refer to Figure 2) in future research.

From the summary of studies done by researchers in Table 5, the management approach success factor emphasized on the commitment and support from top management was seen to be a successful implementation of the environmental management systems beginning from the palm oil plantation itself. The researchers argued that without top management supports, failure of any environmental management system is likely. Employees must be able to trust management's decision for ISO 14001 implementation and feel the continuing support for the decision. A successful implementation of ISO 14001-based environmental management systems also requires changes within an organisation in structure with clearly defined responsibilities, authorities, and communication channels throughout the supply networks. Due to growing pressure from customers, governments and other stakeholders to the companies to demonstrate their commitment to environment, ISO 14001 certification is seen as an evidence of such a commitment. This helps to strengthen team spirit and venture business into the international market. However, regular monitoring needs to be done by using appropriate monitoring and measuring equipments to improve the processes. In order to do so, the authors suggest that the provided template questions should be answered to assess to sustainable industrial systems and benchmarking of sustainability indicators as critical success factors of the supply network performance should be an important element.

Critical Success Factors	**References**
1. **Management Approach** Top management approach can be seen in the form of commitment and support, appropriate environmental policy that is accepted by every employee in the organisation, and regular management reviews.	A Zutshi, AS Sohal. (2004), Ambika, Z, Amrik, S. (2004), Clement, R.B. (1996), Kuhre WL. (1995), Lim-Teck G, Lee-PT. (2001), Nalini, G., et al. (2004), Wee & HA Quazi (2005).
2. **Organizational Change** Organisational changes associated with the implementation can lead to a continual improvement in environmental performance.	Clement, R.B. (1996), Lim-Teck G, Lee-PT. (2001).
3. **External and Social Aspects** The effective development and implementation of ISO 14001 -based EMS is influenced to a great extent by external and social aspects that include environmental legislation, market pressure, customer requirements, and employee relations.	Lin CM. (1995). Sayre D. (1996), Thornton R. (2000).
4. **Technical Aspects** The effective implementation of ISO 14001-based EMS in technical aspects include assistance from environmental specialists, availability of monitoring and measuring equipment, and the production process enhancement.	Kuhre WL. (1995), Clement, R.B. (1996), Lin CM. (1995).

Table 5: Critical Success Factors by References

6 Conclusions

This case study was to explore the need to integrate sustainability considerations into organisational structures and supply networks. The aim was to propose a framework to be used for the design of sustainable industrial systems that can translate requirements to deliver sustainability solutions. Hence, the relationship and linkages between sustainability, organisational structures and supply networks need to be better understood and therefore more research and case studies are needed. It is intended that the template of sustainability questions created can be used to inform the design of supply networks intended to deliver more sustainable products. In addition, we anticipate that they could be used to inform benchmarking activities as critical success factors to aid decision making and the measurement of supply networks performance. The novelty of this case study was that it identifies the significance of sustainable industry systems from the viewpoint of the enterprise engineering framework model and provides a basis for evaluations with respect to the environmental and socio-economic impacts assessments in the future.

The adaptation of the enterprise engineering framework towards the design of sustainable industrial systems can be further analysed with a case study on the life cycle assessment as the enterprise operating system. The expected outcomes can be compared to investigate the importance between environmental management systems and life cycle assessment which later will be coupled to address two major research questions:-

1. How can sustainability be defined and applied to the supply networks of Malaysian palm oil industry?
2. What are the capabilities needed to develop sustainable new products, and how might such capabilities be assessed?

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Considering sustainable impacts of suppliers throughout the product life cycle in the pursue of a sustainable vision

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Abstract: Increasing environmental concern and a raising number of legislations is forcing organizations to rethink their business. As the product development process mainly determines the performance of a product and future impacts throughout the life cycle, organizations need to implement considerations of sustainability. This paper presents a method for prioritizing and developing suppliers in order to reach a sustainable vision, i.e. a predefined description of how an organization stipulates the sustainability performance of its future products. Mapping the supplier-base onto the phases of the product life cycle together with considerations on their purchasing volume provides an overview of suppliers' strategic influence on the product. Combined with a life cycle analysis this provides a graphical representation of the suppliers' sustainable importance during the product life cycle. Evaluating suppliers with the highest sustainable importance against their development potential enables a strategic layout of how suppliers need to develop in order to reach a sustainable vision. .

Keyword: Life cycle assessment, supply chain management, product development, sustainability.

1 Introduction

Increasing environmental concern together with a raising number of regulations and legislations are forcing organizations to rethink their business [1]. Organizations are facing sustainable challenges such as approaching the thresholds of irreversible ecosystems, waste problems and impacts on human health as a consequence of the current consumption and production paradigm [2][3]. Consequently, Original Equipment Manufacturers (OEM's) must include sustainable thinking into the development process of these products. Current literature and methods focus on minimizing environmental impacts of existing products or evaluating new product concepts against a set of environmental criteria. In the context of the product development process [4] existing methods for sustainable product development are applied to achieve alternations of product functions or to prioritize product concepts. To achieve an enhanced focus on sustainability organizations need to include considerations of sustainability earlier in the product development process. This is the basis of reaching sustainability, which is defined as meeting the needs of firm's direct and indirect stakeholders without compromising its ability to meet the needs of future stakeholders as well [3]. As the majority of a product is provided by suppliers [5], the concept of sustainability needs to be expanded to the supply chain consequently. OEMs concentrate on their core competences [6] and need to integrate suppliers in their process. In order to align the goals of the different parties, OEMs resort to inter-organizational supplier development activities. OEMs need to prioritize their investments in supplier activities [7], as they do not want to see their supply chains becoming greener on expense of poorer business performance [8]. The selection and management of green supplier development will require significant planning and management [8], which makes a classification of the suppliers indispensable. In this context, Bai & Sarkis [8] stated that there is a gap in literature on how an organization can manage its supplier development program with a sustainable focus. However, combined sustainable supply chain approaches do not consider the supplier development potential Bai & Sarkis [8], which indicates the longterm performance according to established Supply Chain Management (SCM) literature [5]. The SCM approaches do not aim specifically on sustainability and diverted supply strategies for specific commodities [5]. As a result, the corporate performance along the environmental dimension of the supplier development activities over all commodities is not taken into account. This precludes for a methodology to answer the central research question of this paper:

How can organizations (OEMs) prioritize their supplier development activities to achieve a sustainable vision with their suppliers?

The developed method consists of six steps, which lay out a strategy for supplier development activities with the goal of a shared sustainable vision. Therefore, a LCA is performed to present the environmental impacts and resource consumption of each life cycle phase (Step 1). The mapping of suppliers to the life cycle phases (Step 2) in combination with the elaboration of their supply volume (Step 3) result in an indication of the environmental impacts and resource consumption for each supplier (Step 4). Besides, the supplier development potential of these selected suppliers is elaborated (Step 5), so that the last step leads to a strategic layout of supplier development activities (Step 6). This layout is based on the current environmental impacts and resource consumption of a supplier and on the further potential of a supplier. To set the terminological basis for the development of the method this paper, introduces the relevant terms – sustainable vision, life cycle assessment, and product development process and supply chain management – in related literature (paragraph 2). Subsequently, the method is developed (paragraph 3) and applied on thermostats for family houses as an example (paragraph 4). Finally, concluding remarks and further work are presented.

2 Related literature

2.1 Sustainable Vision

As mentioned in the introduction creating a sustainable vision for an organization and its products is one way of achieving a higher degree of eco-innovation [9]. According to Nanus [10] a vision is defined as a realistic, credible, attractive future for an organization.

A vision has to be realistic to be a meaningful point of orientation for the organization, it has to be credible for employees of the organization to believe in it, it must be attractive in order to motivate and inspire the employees to strive for perfection. Lastly a vision drive an organization past the current status and must therefore depict a future ambition. The Natural Step (TNS) [11] suggests a method for creating a sustainable vision with a concomitant action plan and sub-targets. TNS is based on an understanding of the current sustainable challenge as a funnel where resources are becoming more and more scarce due to the current rate of consumption. This implicates an increasing pressure on environment and society. In order to accommodate this TNS defines four sustainable principles; (i) eliminate increasing concentrations of substances extracted from the earth's crust, (ii) eliminate increasing concentrations of substances produced by society, (iii) eliminate physical degradation of nature, and (iv) eliminate barriers that undermine people's ability to meet their needs. The vision creation process defined by TNS is as follows (Figure 1). Once a company has obtained a basic understanding of sustainability (A), a sustainable vision is created based on the above mentioned principles (C) and on the basis of a baseline analysis of the company's current activities and their environmental impacts (B). The principle of backcasting is applied to create an action plan starting from the current baseline of the company towards the vision (D) [11].

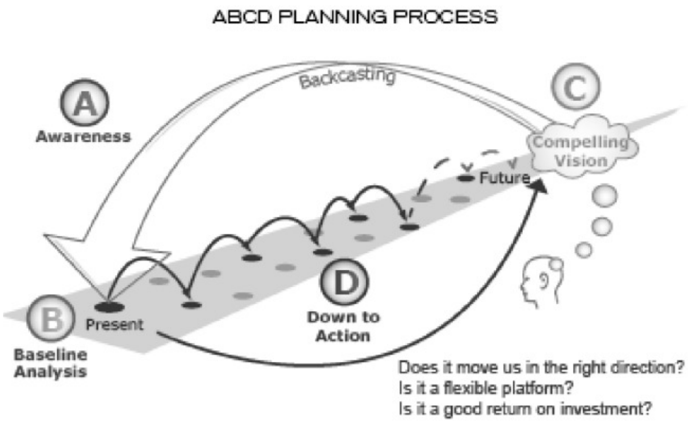

Figure 1 The iterative ABCD-process of The Natural Step [11].

2.2 *Product Development Process*

The majority of a product's performance and future impacts throughout the life cycle are determined in the early phases of product development [4]. According to Pahl and Beitz [4] the product development process consists of four phases, planning and task clarification, conceptual design, embodiment design and detail design [4] [12]. In the early phases of the product development (i.e. planning and task clarification and conceptual design) the requirement list and functional analysis is established. This means, that organizations need to implement considerations of sustainability early to significantly affect the overall functionality and the initial product concepts as the latitude of development is constantly decreasing over time [13].

2.3 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a commonly applied and standardized eco-design tool for quantifying the environmental impacts of a product and its related services throughout the whole product life cycle. It identifies the resource consumption associated with a product and the environmental impacts connected to energy consumption and waste streams by quantifying these measures in relation to the environmental impact of these substances [14]. Additionally, the impacts on the working environment (i.e. human health) can be analyzed. Wenzel, Hauschild, and Alting [14] propose to consider the following life cycle phases when performing a LCA; *extraction of raw material, production of materials, product manufacturing, use and disposal.*

LCA is chosen as one of the backbones of the presented method since:

- it is widespread and known by most organizations,
- it clearly indicates which impacts are associated with a product and to which life cycle phases they belong to,
- it quantifies the environmental impacts allowing for an "accurate" supplier analysis,
- and it presents a suitable definition of the life cycle phases.

LCA will be applied as representation of the environmental impacts, which can then be combined with supplier volume to analyze the environmental impacts connected to each supplier.

2.4 Supply Chain Management

With suppliers affecting the corporate performance at the environmental dimension [15], considerations of sustainability need to be implemented in supply chain management (SCM). Referring to the five steps of SCM – configuration of the supplier base, supplier evaluation, supplier development, supplier integration and supplier assessment [16] – the supplier development is a critical aspect of the inter-organizational focus (customersupplier-relationship) of the SCM [17]. Based on the supplier evaluation development activities intend the increase of the corporate performance [16], which is affected by the size and the available resources of the suppliers [17]. Many suppliers, according to Seuring & Muller [17] are small and do not have the necessary resources to address the serious environmental issues they are facing [17]. As a result, OEMs have to prioritize their investments in supplier development activities [7], which requires a classification of suppliers.

A generic SCM approach differentiates between supplier and commodity, which are described through two separate portfolios [5]. The commodity is evaluated against the supply risk and the supply volume. Thereby, the supply risk is elaborated through a checklist with the complexity, uncertainty and specificity of the commodity. In contrast to that, the supply volume is the sum of all purchases of the specific commodity on an annual timeline. Based on these two dimensions four different types of suppliers are deduced; standard-, bottleneck-, core- and strategic-commodities [5]. In contrast to that, the evaluation of the supplier is based on the supplier development potential and the supply risk. The latter is, compared to the supply risk of the commodity, related to the structure of the supply market and the customer-supplier-data (e.g. supplier capacity, development of demand etc.). The supplier development potential is deduced of an evaluation based on a checklist, which is questioning the know-how of production, Considering sustainable impacts of suppliers throughout the product life cycle in the pursue of a sustainable vision logistics and development of a specific supplier. With these indicators Wildemann [5] is drawing a portfolio with four fields of different suppliers; standard-, bottleneck-, core- and strategic-supplier. Finally, the classification of the four different types of commodities and suppliers are used as axis of a two dimensional portfolio for the deduction of strategies for different constellations of suppliers and commodities [5]. As the deduced strategy refers to a specific commodity, the holistic approach of the sustainable vision is not supported. With the incorporated vision, the consideration of sustainability is not limited to one commodity, but to the business core of a supplier, which is taking the corporate performance along with the environmental dimension into account. Although, the approach gives evidence, that the supplier development potential is important for the deduction of strategies for the cooperation of OEMs and suppliers.

An approach, which is focused on the sustainability of supply chains, is deduced by Handfield [15] based on the Analytical Hierarchy Process (AHP). Originally the AHP was devised to provide a framework for solving different types of multi-criterion decision problems. Based on a substantial list of environmental indictors the AHP is used as a decision support model to evaluate the relative importance of various environmental traits and to assess the relative performance of several suppliers along these traits [15]. Therewith, this approach is supporting a decision, which is based on the current performance of a supplier. However, the supplier development potential is not assessed, so that prioritization of supplier development activities is solely based on the current performance of a supplier. Although, the list of environmental indictors used by Handfield gives evidence of considerable aspects [15], which could be the basis for specific supplier development activities.

3 Methodology

The method prioritizes suppliers and lay out a strategy for how suppliers can be developed to fulfill a sustainable vision. This is done by evaluating how much each central supplier accounts for of the environmental impacts and the resource consumption by combining a LCA with the mapping of suppliers to the different life cycle phases. Suppliers are here defined as organizations providing a product. The method consists of six steps, step 1 to 3 are independent and can be performed simultaneously or in random order. Since this method prioritizes suppliers in becoming sustainable, the method must be an iterative process starting with the most central suppliers. Also, the method assumes that a sustainable vision is already created as advised by Boisvert, Leung, Mackrael, Park, & Purcell [11].

Step 1: A LCA is performed for the analyzed product/product family. If already conducted, the results of the LCA must be collected and interpreted. The LCA provides an overview of the environmental impacts and resource consumption associated with a product, and it illustrates which life cycle phases these originate from.

Step 2: Suppliers are mapped onto the product life cycle phases. Mapping the suppliers to the product life cycle phases provides an initial overview of how the supplier network is distributed onto the different life cycle phases. Some suppliers may appear in more than one phase. The mapping is represented graphically to give an easy overview (Figure 4).

Step 3: Each supplier is evaluated in terms of volume. The volume is defined as the purchases of an OEM at one specific supplier referring to all life cycle phases [5]. Jorgensen, Behncke, Lindemann.

Thereby, it indicates the influence of a supplier and is represented in relative numbers, which enables a future evaluation of the LCA in relation to the supplier importance. Additionally, evaluating the volume of suppliers enables an initial screening to identify the substantial suppliers. The following criteria assist this screening process:

- Suppliers with a high environmental impact or resource consumption in one life cycle phase,
- Suppliers with a high overall environmental impact or resource consumption.
- Suppliers without the control of the organization must be excluded from this method and assessed with special attention (e.g. electricity organizations, …),
- Suppliers with low volume have a low influence on the environmental impacts and resource consumption and can therefore be neglected in the first iterations of the method.

Step 4: The LCA is combined with the relative numbers for the supplier volume. This is done by multiplying the two figures. A depiction of the environmental impacts and resource consumption associated to each supplier are hereby created. Thus, it can be evaluated, which suppliers account for most of the impacts and the consumption and they accordingly be prioritized.

Step 5: The development potential of each supplier is identified. Therefore, a checklist based evaluation is employed, which is based on three indicators; know-how in development, logistics and production [5]. By analyzing the development potential of the substantial suppliers, it is possible to identify which development strategies to choose for each supplier for them to fulfill the sustainable vision of the OEM.

Step 6: Finally, the strategy for the suppliers' fulfillment of the sustainable vision is rolled out. This strategy is based upon the development potential of suppliers (step 5) and the graphical representation of the influence of the suppliers on the environmental impacts and resource consumption (step 4). To assist the creation of the strategy roll out the following guidelines can be applied:

- Suppliers with low development potential have slowly increasing slope,
- Suppliers with high environmental impacts and resource consumption must be involved early in the vision fulfillment process.

4 Example

To illustrate the method and as an initial validation, the six-step approach is here applied on an example. In the example the method is applied on heat sensors and valves (commonly referred to as thermostats) for family houses, and the related supply chain. Due to confidentiality the data is modified.

Step 1: A LCA was collected for the thermostat including calculations of the heat consumption during the use stage. To be able to compare the result for different heat sources and for different thermostats, the functional unit for the analysis was defined as follows: Ensuring a comfortable indoor temperature assuming a standard household (2,1 persons) of 130m2 with 8 radiators installed each with a thermostat attached (equal to 8 valves and 8 sensors). Additionally it was assumed that the use stage lasts for 20 years based on company data. As an example the diagram for the environmental impacts of the functional unit divided onto the life cycles phases are shown below. The results shown in Considering sustainable impacts of suppliers throughout the product life cycle in the pursue of a sustainable vision the diagram are normalized and weighted (PET) meaning that the environmental impacts for the functional unit first are compared with the corresponding global impact and then weighted against the severity of the impact (Figure 2).

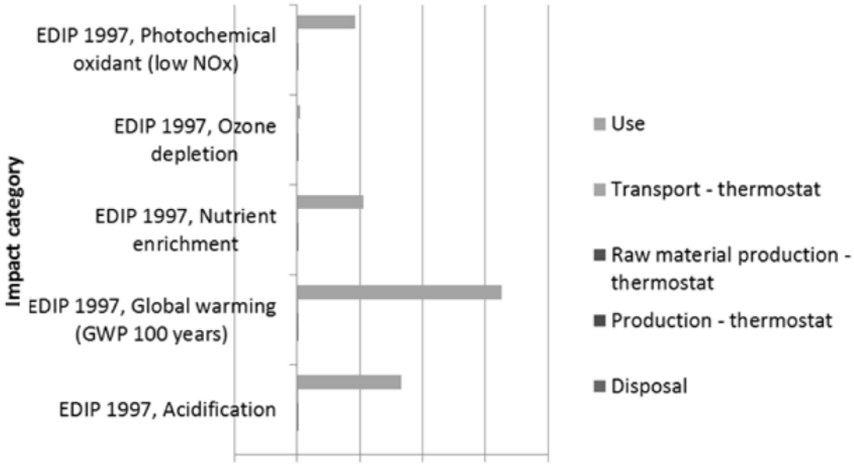

Figure 2 The environmental impacts for each life cycle phase of the thermostats.

Step 2: Suppliers are in a graphical representation mapped to the different life cycle phases (Figure 3). The mapping is done by analyzing to which phases each supplier deliver commodities. A supplier might appear in more than one life cycle phase (e.g. supplier 3 deliverers parts during product manufacturing and recovers the same parts during disposal). The mapping is produced on the background of a supplier list, which is extracted of the companies' ERP-System (Enterprise Resource Planning System).

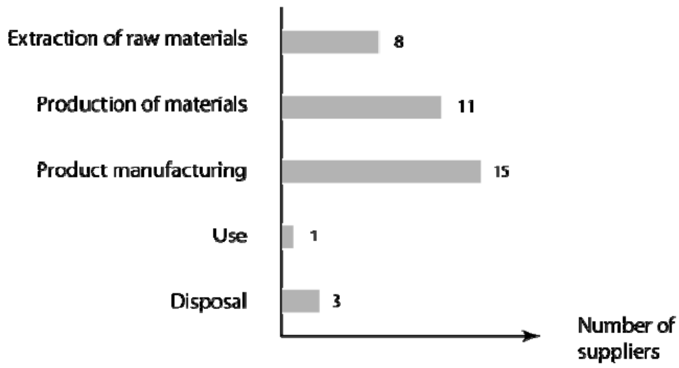

Figure 3 Number of suppliers involved in each life cycle phase.

Step 3: Based on the classification of the suppliers to the corresponding life cycle phases (Figure 4), the volume is considering the impact of a specific supplier throughout the complete life cycle. Therewith, the volume is the percentage of purchases of an OEM at a specific supplier in relation to the total volume of the OEM in terms of capital (Figure 4).

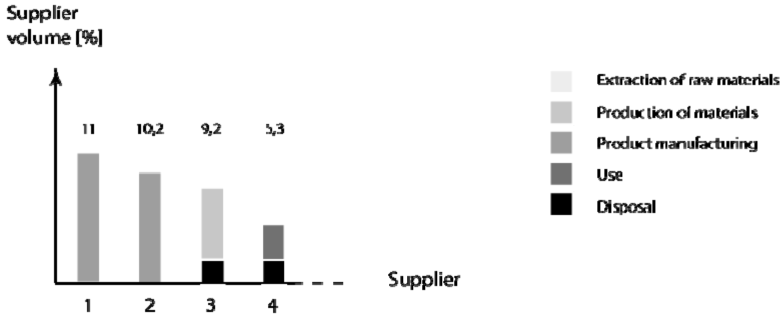

Figure 4 The volume of each supplier in percent.

Step 4: For the environmental impacts and the resource consumption, it is calculated how much each supplier account for. This is simply done by multiplying the environmental impacts (Figure 3) and the resource consumption (Figure 2) with the supplier volume (Figure 4). A resulting graph will then display the environmental impact for each substantial supplier (Figure 5).

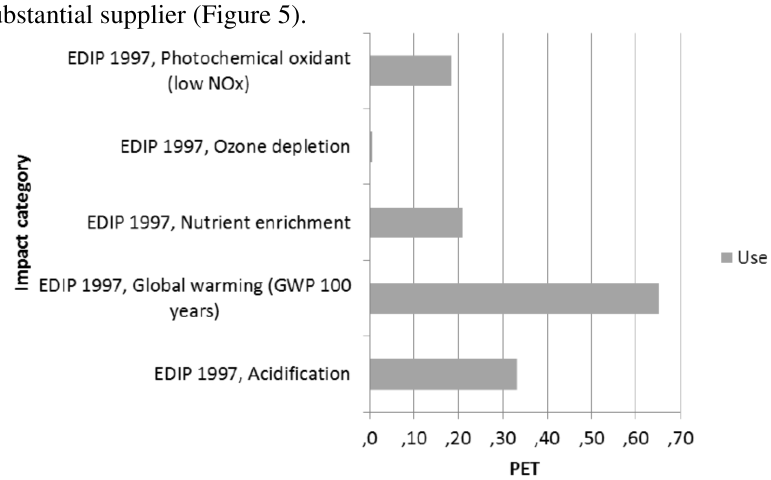

Figure 5 The environmental impact related to Supplier 1

Step 5: The development potential of suppliers is analyzed on a top level based on the checklist [5]. Thereby, the supplier is evaluated through the know-how in production, development and logistics. As a result, the identification of suppliers with a high and a low development potential, lead to qualitative classification of suppliers in two categories. As a result, suppliers with a high potential have a faster development towards the sustainable vision of the OEM than suppliers with a low potential.

Step 6: The last step is combining the information of the previous steps to a strategic layout of a supplier development plan (Figure 6). As a result, suppliers with a high overall environmental impact (Figure 5) relative to other suppliers are included in the layout on an earlier stage, while suppliers with a high development potential are characterized through a higher slope.

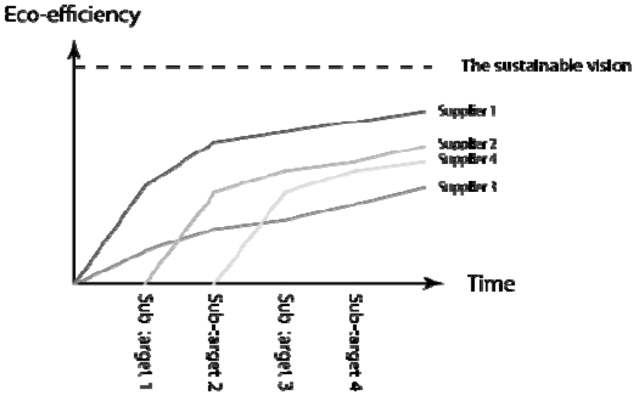

Figure 6 The strategic layout of suppliers to fulfill a shared sustainable vision

5 Conclusion and further work

For a vast majority of products, most components are delivered by suppliers [5] [6] and they do therefore have a direct influence on the environmental impacts and the resource consumption related to the product. Consequently, this paper suggests a method for how organizations can prioritize among suppliers to develop a strategic plan for its suppliers to reach a shared vision. The method highlights which suppliers account for the biggest impacts and which have the highest development potential and hereby which suppliers need to be integrated first in becoming sustainable. The method has the advantage of relying on a sustainable vision and a concomitant action plan which motivates organizations to consider sustainability early in the product development process. Additionally, the method builds on existing methods (LCA, SCM) which makes it easy to apply for organizations familiar to these methods. Though, since the method includes a LCA it is retro-perspective, however the consideration of the supplier development potential adds a future perspective. To avoid a focus on minimization of environmental impacts of products the method must only be used for prioritizing suppliers and not as a tool for creating the vision or product ideas. Thinking in terms of minimization will not address the root cause of the environmental impact only decrease its impact. This paper presents the initial idea of a prioritization tool and it has been applied on the data from industry case. Though, the strategy planning of the method has not yet been evaluated in a real-life context, which is necessary to identify the benefits of the method. Also, activities for implementing sustainable thinking at suppliers are to be developed in order to provide organizations with a tool box after the prioritization. In order to focus the evaluation of the supplier development potential based on sustainability the list of environmental indicators presented by Handfield [15] provides a solid basis for further elaboration. Moreover, these indicators give information about potential supplier development activities. A last point to be investigated is if a Life Cycle Check (LCC) or other less comprehensive tools can be modified and applied instead of the LCA methodology.

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Chapter 4
Collaboration

Semantic-based approach for the integration of product design and numerical simulation

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Abstract: Nowadays, the increasing heterogeneity of CAx (Computer Aided x) applications and Product Lifecycle Management (PLM) systems raises the problem of knowledge management in information and Communication Technology based applications. This appears to be a real barrier for effective collaboration between experts and tools involved in product development process. PLM systems are considered strategic tools to allow collaboration within the product development process, but they still fall short of providing the full range of desired functionalities. This paper proposes a collaborative Semantic Web environment, using a Relationship Manager, to improve the integration between CAx applications and usual data management applications, especially between CAD (Computer Aided Design), CAE (Computer Aided Engineering) tools and data management applications. The Relationship Manager is used as a centralized process that enables verification and validation of design decision-making and numerical simulation results, in accordance with the functional requirements of the product. The aim of the paper is to discuss the collaborative design process as considered in our work, and then introduce the components of the proposed Relationship Manager (RsM), presenting the functional and technical aspects of the proposed Semantic Web approach and related platform to link requirements engineering, product design and numerical simulation.

Keyword: Product Design, Numerical Simulation, Engineering Knowledge, Data Sharing, Semantic Web

1 Introduction

The deep changes noticed in the past three decades within the industrial processes have allowed major improvements in product design, numerical simulation and manufacturing engineering. These changes have taken benefit of the large development of Information and Communication Technology (ICT) in the field of Product Lifecycle Management (PLM) and collaborative design. In [1], Sohlenius quoted that "In order to encourage the emergence of innovative solutions and to reduce product time cycle development, companies need to develop collaborative product design". Over time, numerous digital solutions (Computer Aided (CAx) applications, Product Data Management (PDM) and PLM systems have emerged as the result of the rapid evolution of digital engineering software, and as supports to engineering activities focused on product-process integration. Nowadays, there exist efficient methods and appropriate systems at many phases of the product lifecycle, i.e. Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacturing (CAM), Simulation Data Management (SDM), Enterprise Resource Planning (ERP) systems... However, the links from one phase to another (in terms of management of product data of each field of expertise) are often not operational thus their full integration not fully effective [2].

The extensive use of CAx systems, integrating product development processes, has resulted in a huge increase of the data volume generated. The issue of collaborative knowledge management and exchange during the product development process is still a hot topic. Product Data Management is defined by two main goals: first, providing the right data at the right time with enough semantic objects for its use in a given activity [3], second, providing information in accordance with the status of the developed product [4]. Although much research work has been performed in this field, efforts are still needed to improve the existing solutions to establish a more efficient and more effective management of design data and knowledge. In order to federate and manage data and information from various phases of the product lifecycle, the main vendors of the PLM market seem, step by step, to be able to provide fairly consistent digital engineering applications integrated with their main PLM system. Still, the main limit remains the technological constraints of the vendors, reducing the interoperability level of these applications. Among other consequences, the lack of interoperability leads to duplication of data and/or merging of data from various repositories to build a common digital repository or a knowledge base, for product-process knowledge integration purposes.

On the other hand, the main challenge for companies today, in terms of knowledge management, is to maximize the benefits from the information assets they have. The aim is to achieve this through an intelligent management and efficient capitalization of these assets for adequate reuse by the right person at the right time. In a collaborative design approach, the main target in such a context is to provide digital support to any design actor, doer as well as decision maker, to access any data/information he/she requires. The data must be available across application borders, should be easy to manipulate for the right purpose, and should interface with other data, resources and related metadata for knowledge capitalization and knowledge reuse purposes. Currently, the right question today is not whether enough information is available, but rather how to manage optimally that information and knowledge, when it is distributed worldwide and stored on heterogeneous applications. The idea in the proposed research work is to take advantage from existing technologies and concepts from the World Wide Web (WWW) and the

Semantic Web (SW). The main purpose is to improve engineering data and knowledge management by providing designers, decision makers, projects' team members based on a computer supported environment -a Relationship Manager (RsM) - to link, retrieve and process design data, metadata and resources. The Relationship Manager (RsM) uses Ontology, Resource Description Framework (RDF) and other Semantic Web (SW) technologies to integrate a set of data and knowledge sources from various digital engineering applications. It links in real time and across applications borders lifecycle data and metadata, thus providing designers with a knowledge base in support of the product lifecycle activities.

The next section discusses the product development process and gives details on what is considered as being relevant data and knowledge in the proposed approach. Section 3 presents the Semantic Web approach, its use for various purposes in the field of PLM, engineering data and knowledge management. Finally, section 4 illustrates the Semantic Web environment realizing the Relationship Manager approach.

2 Analysis of the product development process

Every product goes through three main steps in its lifecycle: the Beginning Of Life (BOL), the Middle Of Life (MOL) and the End Of Life (EOL) [5]. The proposed approach is mainly focused on data and knowledge of the BOL, but can still be applied to the MOL. In the product BOL also known as the development phase, several digital engineering applications in support to design activities and methodologies are considered.

As shown on Figure 1 (corresponding to the BOL), the phases of product development process include needs clarification and related requirements and constraints (supported by Requirements Management Systems); preliminary and detailed design (supported by CAD applications and managed by PDM and PLM systems); numerical analysis (simulation) to verify and validate the design (supported by CAE applications and managed by SDM systems). Given the set of digital engineering applications and the amount of data involved in this step, successful product development process requires: good collaboration between project team members, and effective interoperability between applications and systems in support of the sharing and exchange of data and knowledge handled and stored in heterogeneous CAx applications and managed by PLM, PDM and SDM systems. From the needs clarification to the validation of the solution fulfilling theses needs (at numerical analysis level) or from the preliminary design and detailed design stages in terms of CAD models, product data evolve with a given set of semantic relationships, from one design stage to another. Being able to manage the change of engineering knowledge during the product design progress and establishing clear traceability between requirements specifications and design solutions, as well as elements of decision making in relation with the choices at a given moment, remains an huge stake and a key challenge for all stakeholders involved in the product development process.

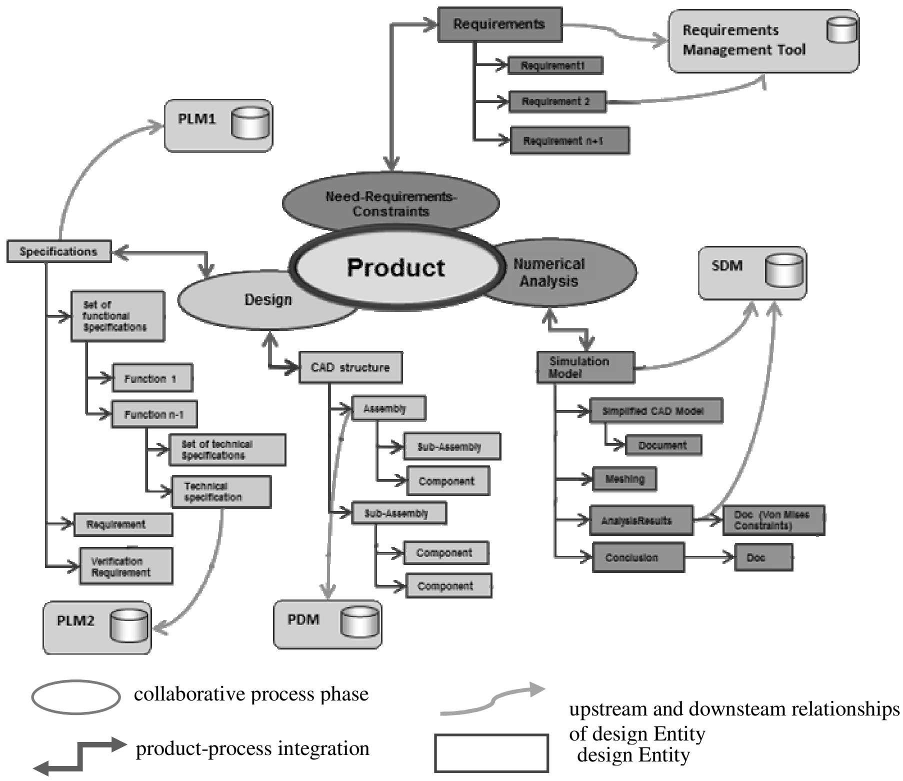

Figure 1 View of a collaborative design process with product data and relationships

What is considered as being product data in this work? In [5], the product data is defined as "all the information assets of a product from its design to its dismantling". In [6], the author describes "data" as an objective entity, explicit and non-contextualized, while "information" is a subjective and contextualized data. The latter considers data and information under the term "product data" and defines it as any entity allowing a task of the product development process to describe the product throughout its life cycle. In this research approach, product data is considered as being "any structural-functional or behavioral entity, required by design team members at all process levels, to understand, verify and validate the product, in all its variations, throughout its lifecycle.

In addition, the whole data of a given product in a given company constitute a digital repository, which every company aims at managing in an efficient way, as their main industrial and business assets [7]. Formalized product data, enriched by a set of semantic relationships, as shown on Figure 2, represent capitalized engineering knowledge that can be reused in a similar design context, or even taken as a reference basis for other design projects.

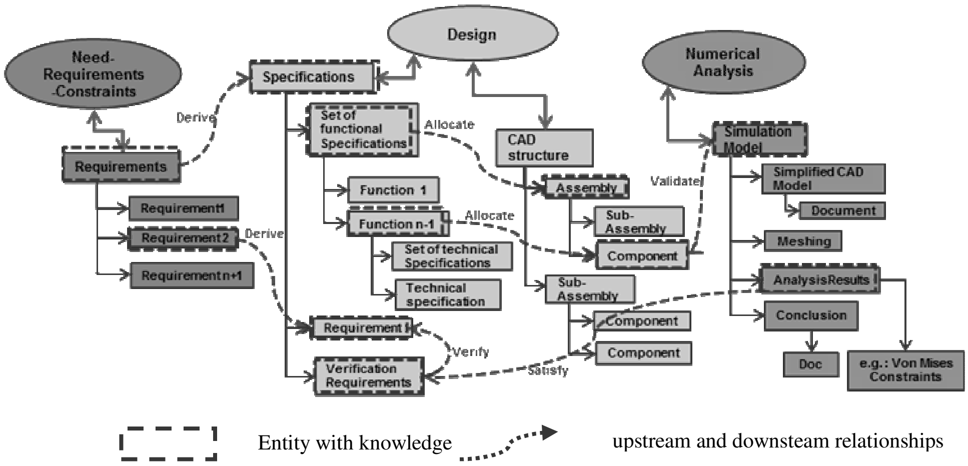

Figure 2 Illustration of design knowledge in relation with design Entity

2.1 Data typology in digital repository

The analysis of digital repository revealed mainly two categories of data related to design: structured data and unstructured data. Structured data, usually defined according to fixed product models, supporting design information based on clear and validated standards, are mostly created and handled by usual digital applications of the design chain (CAx, PDM…).. In contrast, unstructured data, embedded in files, personal notes, memoranda, design draft, capitalized decision-making, capitalized design rationale, tutorials in which knowledge is usually hidden, are still not fully managed by common collaborative systems. These data, in fact, accessible through legacy formats with a well defined structure, are currently unstructured from the perspective of a user, working (for instance) with a PLM, as data source.

In between these two categories of data, a third category of data, called semi-structured data, is addressed in this works. The idea is to provide design team members with data whose structure is initially unfrozen, data that can evolve with the design activity. Such a data gives the designers the possibility to contribute with their own knowledge, in order to enrich the available data, and share the thus created knowledge assets with other designers for capitalization and reuse purposes. To this end, the focus is on improving the current management of engineering knowledge, by providing a new approach to knowledge capitalization and reuse based on a Relationship Manager (RsM). The RsM, currently offers functionalities to designers in order to search, capture, represent, view data and knowledge, and to link unstructured data to structured data, thereby generating (unfrozen) semi-structured data, and enabling the emergence of a encompassing knowledge base, dedicated to each designer, but responding to the knowledge management need at a global level. As currently implemented, the RsM approach is based on Semantic Web (SW) technologies to link the considered data, so as to improve digital engineering applications interoperability for knowledge management.

3 Using Semantic Web technologies to improve engineering knowledge management

The World Wide Web has radically changed the way of sharing knowledge by lowering the barrier to publishing and accessing documents as part of a global information space [8]. Computers give two practical techniques for the man-knowledge interface [9]: one is hypertext, in which links between pieces of text (or other media) mimic human association of ideas; the other is text retrieval, which allows associations to be deduced from the content of text. Hypertext links allow users to navigate this information space using Web browsers, while search engines index the documents and analyze the structure of links between them to infer potential relevance to users' search queries [10].

3.1 The Semantic Web and related work

As defined in [11], "The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation". The World Wide Web Consortium (W3C) is the international standardization body that develops a set of protocols, standards, guidelines, and a set of technologies to achieve the vision of the Semantic Web. The Semantic Web (SW) is based on well known approaches and technologies including Ontology, XML (eXtensible Markup Language), RDF (Resource Description Framework) and RDFS (RDF Schema) used to control RDF descriptions, URI (Uniform Resource Identifier)…

In the PLM field, various approaches [12, 13] have been carried out in product design showing for instance the significant contributions that ontological models can make to interoperability between software platforms. Other works also focus on the integration of the data and knowledge in a collaborative design [14]. Some works have been conducted on the implementation of ontology in the model of an existing product [15], for the merging of product lifecycle models [16], for interoperability, and for the exploitation of the various product lifecycle data as input for new product development processes [17]. In a preliminary attempt at using the Web Semantic paradigm, especially the Web Ontology Language (OWL) for domain-specific engineering knowledge modeling and reuse, Zhang and Yin [18] proposed an ontology-based modeling process, evolving along five consecutive layers. These layers are: knowledge elicitation, product modeling, ontology modeling, knowledge reuse, and knowledge application, with diverse knowledge assets wrapped up as ontology-based Web Services to enable knowledge consumption, reuse and supply on the Semantic Web. In the field of EAI (Enterprise Application Integration) Middleware, Sauermann [19] proposed a Semantic Desktop, where he transferred and applied existing Semantic Web technologies to a personal computer. In that approach, resources on the computer are addressed with a URI scheme and their metadata is converted to RDF.

Each of these works covers specific areas and technologies addressed by the RsM (Relationship Manager) and just lay the basis for developing such a semantic-based collaborative environment for engineering knowledge management. Compared to the Semantic Desktop proposed in [19], and designed to be the middleware (middleware = system that handles "Data Integration", with the goal to access data from a heterogeneous set of systems and publish them in a uniform way) on a single user's desktop, the RsM will act, to some extents as a Middleware in support of engineering knowledge management.

4 The Relationship Manager (RsM)

The Relationship Manager (RsM) is based on the following hypothesis:

- every data, every resource containing the data, and related metadata within the product lifecycle has a URI wherever it is stored,
- metadata and resources can be represented and structured through a RDF format using Subject-Predicate-Object statement (See Figure 3).

The goal of the RsM is not to reconsider existing functionalities in CAx systems and PDM or PLM applications. But it aims at keeping and integrating a set of existing digital engineering applications into a collaborative data management approach through the use of a common data format based on Semantic Web (SW) technologies. The RsM allows search, representation, visualization and linking of data and knowledge from multidisciplinary engineering fields, thus acting like a data integration application.

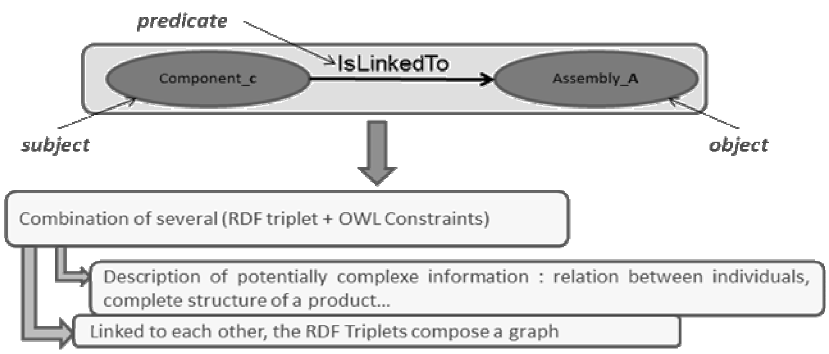

Figure 3 Subject-Predicate-Object statement : application in the RsM approach

4.1 The RsM main functionalities

As shown on Figure 4, the RsM is specified to support at least four main use cases: ***Search for Entity, Create Relationship, View Entity and Relationship, Enrich Entity***.

- Search for Entity: through the GUI (Graphical User Interface), a user can perform two types of searches on Entities: either ***Full-Text Search*** or ***Advanced Search*** where he/she can fill in more details on the search criteria (e.g. Entity name, name or id of the referring application or platform…) if known,
- Create Relationship : during a ***Session***, the user is given the possibility to select two or more ***Entities***, drag them to a workspace where s/he can create a relationship between two or more of these ***Entities***,

- View Entity and Relationship : Once ***Results*** from a ***Query*** are displayed for the user, as ***RDF Graph***, the user has the possibility to perform some visualization actions on the displayed graph (zooming, selecting nodes of the graph, navigating within the graph, clicking the link to access the related *Business Entity (BE)…*"the term BE will be explained later"),
- Enrich Entity: enrichment could be ***Annotation***, comments, initiation of a Blog or Wiki on a *Relationship Entity (RE),…* The idea is to allow two kinds of enrichment in the RsM: optional enrichment without validation, but with some restrictions; and mandatory enrichment with validation workflow for critical data. Enrichment and change on Business Entities (*BE)* will be made in the related hosting application, a functionality will be developed to allow the edition of *BE* in their native format.

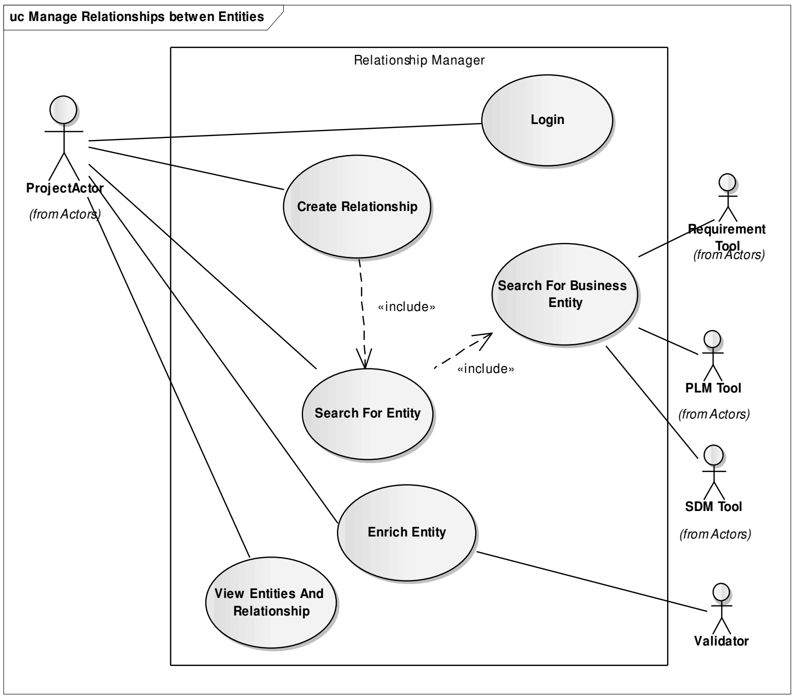

Figure 4 The Relationship Manager main functionalities

4.2 UML static structure model of the RsM

The UML diagram of Figure 5 summarizes the basic objects instantiated in the Relationship Manager approach. The described model is not a product model, but rather a capture of the logical structure of the system. The classes and objects that make up the model, describe what entity is manipulated in our approach, and what attributes and behavior it has.

Thus, the key object in the RsM model is the Entity (*E*). The Entity generalizes both *Business Entity* (*BE*) and *Relationship Entity* (*RE*); *BE* is the object of the model, representing any metadata or resource stored in existing management systems or platform (requirement management applications, PLM, PDM, SDM…), it is represented by a hypertext link to the corresponding data in the business tool; *RE* is the core object of the model, defining the relationship between two *Entities* (E). The structure of a *RE* Object is defined as follow: ***RE = BE-predicate-BE or BE-predicate-RE or RE-predicate-RE***, thus following the description of a RDF Subject-Predicate-Object statement. The *Entity* (*E*), on which a *Query(Q)* is performed, is handled within the *Session (S)* by the user, *ProjectActor (PA)* with a given *ViewPoint (VP)*. The *ViewPoint* is related to the expertise of the design actor, and for now three *ViewPoints* are defined: Requirements Engineering, Product Design, and Numerical Simulation. The Semantic Database aggregates the *RE* objects with hypertext links to the *BE* stored in their respective applications; it also aggregates ontologies related to different engineering activities addressed by the RsM (requirements engineering, product design, numerical simulation). In the RsM, ontologies are used to describe metadata about resources, and possible properties of resources. In addition, the Semantic Database aggregates enrichments (in terms of knowledge) made to the *RE* during creation of relationships; and it also aggregates the search results, allowing any user to access, within limits, the history of the search made within a given *Session (S)*, and also the history related to an *Entity* (*E*).

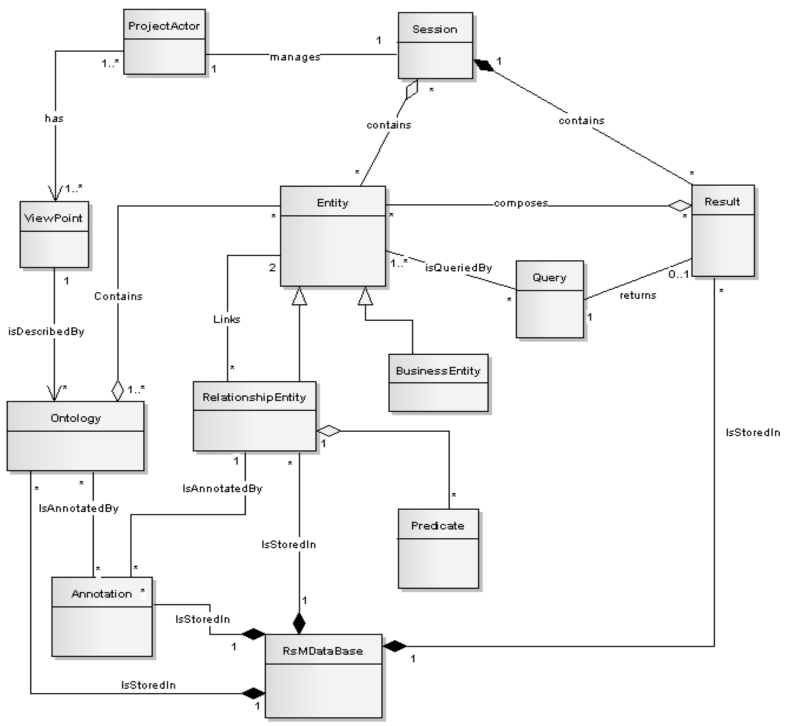

Figure 5 UML domain model of the Relationship Manager

4.3 Implementing a prototype for the RsM

In the implementation of the scenarios describing the RsM use cases, techniques from the SW including URI and RDF are used. Currently, within the RsM, data and resources from requirements management, PDM, PLM, SDM systems are addressed with a URI scheme and their metadata are converted to RDF. This allows (1) creation of relationships between heterogeneous entities from various applications, and (2) access to any entity of the product development process through a common data format. RDF is chosen as data format for all information stored in the RsM Semantic Database since it is well adapted for data integration in Enterprise Architecture Integration. Based on a Uniform Resource Identifier (URI) to identify data, metadata, resources is very convenient. A URI is globally unique. It is not restricted to a local database but can be used worldwide. It contains information about the identification of any Entity. To store a reference to a given entity, just the URI is needed. Information about entities can be queried based on the URI of these entities and everything can be extracted from the identifier.

In the RsM technical aspects, the component playing the interface role in the interrogation of external business applications during a ***Query*** execution is the ***WSXQuery*** module, which is actually a Web Service running a ***PLMXQuery*** from the RsM side. The main constraint is the capacity of the queried business tool or application to receive and execute queries in XML as input, and sending back the result to the RsM ***WSXQuery*** module in XML format. When this is possible, the result in XML is converted to the RDF Format and displayed for the user as an RDF Graph.

5 Conclusion

Regarding the product development process, in order to enable engineering knowledge management approach has been proposed. First, a focus is made on data created and managed during the product development process, and the evolution of these data into knowledge at a certain level of maturity. Second, the various possible relationships between structured data and unstructured data from heterogeneous digital engineering applications are clarified. Their fairly limited management in the field of design data integration, is presented before proposing the concept of semi-structured data for engineering knowledge capitalization and reuse. In the implementation of the proposed approach, a collaborative management environment is specified: the Relationship Manager (RsM) based on Semantic Web (SW) technology. The Relationship Manager allows design team members to link various data from heterogeneous platforms (CAx, PLM, PDM…) and enables the involvment of design stakeholders in engineering knowledge management. In order to carry out the proposed approaches and the RsM architecture, a prototype is being developed and will be tested in future developments for validating the works.

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Numerical representation of interface control documents (ICDs) for collaborative engineering

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Abstract: When designing a complex product in a collaborative engineering context, interface management is a major concern. An interface control document is the main means to avoid assembly errors, misinterpretations and problems in work package coordination. Therefore, in a collaborative engineering environment, the question that arises is: How can we facilitate the management of interfaces and improve the control of documents in a PLM context? This paper proposes a numerical representation of geometrical and functional constraints related to interface control documents. A template typology as well as the corresponding implementation methods for these templates in a CAD environment is suggested as the means to verify the constraints between two subsystems. This numerical format provides engineers with the necessary tools to manage interfaces. Interface control documents become clearer and easier to share with partners. Moreover, these new methods are compatible with designer's work habits.

Keyword: Interface management; interface control document; computer aided; complex product.

1 Introduction

As the production of documents by engineers has increased in volume, their management has been dealt with using product data management (PDM) systems. Another major trend is toward sharing the development of products between distinct organizations. Considering that all the parts and documents are not being produced by a single company, and that a variety of skills and even industries are involved, a significant amount of effort is required to manage the various documents, as in aeronautics. Product data management systems can easily become overwhelmed. Engineers and firms that need to closely manage the shelf life of their products [1] have equipped themselves with product lifecycle management (PLM) systems with one objective: to increase their competitiveness. However, even PLM systems offer limited specific solutions when it comes to managing interfaces.

An important concept for addressing these issues is collaborative engineering, defined by the International Journal of Collaborative Engineering as the study of "the interactive process of engineering collaboration, whereby multiple interested stakeholders resolve conflicts, bargain for individual or collective advantages, agree upon courses of action, and/or attempt to craft joint outcomes which serve their mutual interests"[2].

Challenges arise when dealing with an interface between two different components from different manufacturers. For instance, before assembling two complex aeronautics systems, a number of constraints must be verified. These constraints could be quite varied in nature; some are geometric and dimensional, others are related to mass or assembly. Amongst the problems that occur in this kind of situation, the main issue is the difficulty in the exchange between partners.

Parts generally proceed from different manufacturers, and the documents that define interfaces are numerous and unclear [3]. There are several different types of documents and numeric formats, so firms must maintain a variety of different software packages to continue viable communication with their partners [4]. As a consequence, there is a large degree of heterogeneity within and between interface control documents.

Products have become more and more complex; one person cannot master knowledge in all of the fields required for the successful design of a product [5]. However, the use of different specialists in certain fields can hamper the flow of information between partners (some information in interface control documents are unclear for non-experts) and can interfere with monitoring and verifying the constraints in an interface control document.

The management of numerous technical documents during the development of a product raises issues such as monitoring incoherence in document versions (each partner may not have the same version of a document) [6]. Of course, interface control documents are subject to the same problems and it is especially difficult to monitor constraint verifications.

An interface control document (ICD) should gather all the specifications of an interface between different groups or subsystems; hence it specifies the limits of each group/subsystem and how they connect to each other. An ICD is required to effectively coordinate the specifications provided for different work packages and to drive many phases of the product development effort that in turn feed data into the PLM system. If the ICDs have a numeric representation, then this representation should be unique and clear in addition to being comprehensive and easily understood by non-experts.

Therefore, the current challenges are the management of interfaces and the quality of the interface control documents. This study's main objective is to numerically represent the geometrical and functional constraints from the interface control documents in a distributed collaborative engineering perspective. To reach this goal we explore the possibility of creating some viable links between ICD and CAD files; define a numeric format for ICD's and represent constraints in a numeric format.

This paper proposes a numerical representation of interface control documents in a collaborative engineering context, and presents some numeric templates which represent geometrical and functional constraints from an interface control document. The types, generation and implementation of these templates are described, and their implementation in a CAD environment is presented through an application case.

2 Concept definitions

2.1 Interface and interface control document

An interface is the result of a subsystem division [7]. A complex product is like a set of modules where each module interacts with the others thanks to a set of complex interfaces. Blyler [4] defines an interface as an input-output module linking two systems. R. Sanchez [8] defines an interface as the links between the shared components and subsystems of a product structure. Finally, M.Z. Ouertani and L. Gzara [9] have a minimalist definition; an interface is merely a "connection between two product parts". The different definitions do not convey the importance of interfaces in a product structure or during the design phase. In a collaborative engineering context, the management of interfaces between subsystems is one of the most critical tasks in product design [10] and new product platform development [11]. During the creation of an interface, there are important rules to respect [12]. Interfaces have to respect the balance of forces, conservation of energy, materials and data (information). According to Ullman, design teams initially only deal with the interactions with external objects. Hence, engineers must first work on the most complex interfaces. Each function has to be independent and affect only one critical characteristic of the whole assembly [12].

From there, we define an interface (based on a description from Pimmler and Eppinger [13]) as a coherent set of specifications between two groups. This set of specifications can define a connection, an exchange of energy (pneumatic, electric, hydraulic or mechanic), an exchange of information or an exchange of material. If the two groups are subsystems, one of these subsystems could be external to the system or the two subsystems could both be internal to the system.

All the specifications of an interface are present in a single document: the interface control document. This document defines the limit between subsystems. Blyler [5] recommends documenting the external interfaces (users interactions with the system, system to systems) and internal interfaces (subsystems to subsystems). To properly define an interface, it is important to focus on the functional description which includes the principal characteristics of the connection with the other products. It is possible to complete the description with a design review [5]. Regarding interface management, the first approach is to work directly on the interface specification in a collaborative engineering context. To this end, Areeprayolkij *et al.* [14] propose a method to check interface compatibility by extracting some information from the interface specifications using UML diagrams (Component and Class diagrams). Verification of interface compatibility is executed through the "Component dependency graph"; a graph that shows the relationships between subsystems. Hisarciklilar *et al*. [15] proposed a conflict detection approach for interface management. The objective is to "allow automatic detection of correctness, completeness, connectivity and consistency of the interface definition." To this end, they developed an interface representation that illustrates subsystem connectivity; based on this representation they develop a "generic exception taxonomy of conflicts" in order to be integrated to a collaborative PLM software. Rahmani *et al*. create a new interface classification and the object oriented model of an interface. These tools allow creating a method to check "the compatibility between two interacting systems" [16]. The research project [16] could reduce the number of document (an important issue in a collaborative engineering context) while facilitating the management of interface. With a different approach, Alizon *et al.* use some design structure matrix for the detailed study of interfaces across a product family structure [17]. These previous works all look for an answer to the following question: what information must be shared among the collaborators of any given project? This question can be addressed with a good knowledge of the different interface through their specification or their analysis. Mollison *et al.* remind us that the most important factor is to gather and process information in order to have a good collaboration without spending effort in sharing useless information [18]. Recently, Bettig *et al*, try to answer these two questions "how an interface should be designed and what information should be included in an interface specifications?" Their research project proposes a new representation of module interfaces [19]. Nonetheless, the project presented here attempts to express the interface requirements in a numerical format and using geometrical features generated from CAD software.

2.2 *Product structure*

In product design, it is standard practice to create a structure that allows the definition of subsystems. Incidentally, an interface is a link between subsystems, so the definition of an interface depends on the product structure itself.

A product structure is a description of the meaningful levels of the decomposition of a product into technical objects (greatest common divisor of a product) [6]. In this paper we focus exclusively on engineering systems; these systems are decomposed into simpler subsystems that can be controlled independently [20]. All product structures are dependent on the focus of the description; for instance, Maurino distinguishes between functional, technical, industrial and logistical structures [6]. Each link allows connecting a technical object with the other objects that compose it. Some research projects [21, 4] create new product structures, each one having its own particularity in order to address specific problems. The project investigators develop specific frameworks to provide, among other things, new tools for the engineers.

Several papers present solutions for conflict management between two subsystems while others present new product structure or new "representation" to share information, including Ouertani and Gzara [9], Kusiak [22] and Browning [23]. They propose solutions based on processes, tools or methods to assist designers. For instance, Browning [23] developed "a visual representation of a complex system" with a "design structure matrix" in order to show dependency. However, interface management is rarely introduced in these works, remarks Hisarciklilar *et al*. [15], even though interface management is paramount in conflict management between two subsystems. Moreover, these solutions are like new "modules" in the design process, and are not really integrated with the working habits of designers. Noël *et al,* propose "a new product model to share design information in a collaborative context", where shared data are contained in interfaces and functions. Hence, a better knowledge of the product model allows a better definition for interfaces [24]. Liang *et al*, work on ports ("ports are defined as locations of intended interaction between a component and its environment) in engineering design. They propose a port ontology considering "all three perspectives used in design: form, function and behavior". One of the advantages is for designers because they can "capture and formalize design decisions about all aspects of a component's interface". Moreover ports have an important role in collaborative engineering context, and it is important to communicate "unambiguously" the decisions between different design team about interfaces between subsystems [25]. These two last examples show that work can be done on the product structure or port for engineering design while having an influence on interface management and collaborative engineering.

A product structure allows the defining of a typology, a vocabulary or a level of details for a given product and its defining subsystems and interfaces. So the interfaces specified in the ICD must be defined using a common typology and vocabulary. The numerical formulation of an ICD must also remain coherent with the product structure.

In the next section we present a solution that focuses on interface management to avoid conflicts between two subsystems in an assembly. This solution synthesizes all the geometrical requirements found in an ICD by expressing them through numerical templates materialized in a CAD environment so as to easily integrate with designers' working habits.

3 Templates controlling interface specifications

The numerical representation of an interface control document is developed in three steps. The first step establishes a template typology, the second presents a link between the rigidity of parts and templates, and the last step implements the numerical representation within CAD software.

3.1 Template typology

The literature review (section 2.1) provided a definition of the content of an interface control document (ICD). This project then analyzed the ICD content to identify the various constraints it imposes between different types of elements. The focus was next placed on geometrical constraints, because they constitute the greater part of an ICD, and because they can be exploited in a systematic manner within a CAD system. Geometrical constraints are classified in four classes:

1) Contact constraints: These specify how distinct elements must connect at the interface. Contact constraints are thus established between the same types of elements; this kind of constraint will be verified by contact templates. The principal objective of contact templates is to control the assembly of two products. Usually, an assembly exists between two parts of the same type. For instance, a hydraulic connector from subsystem "A" is to be connected with another hydraulic connector from subsystem "B".
2) Compliance constraints: These constraints control the displacement of different components in one given direction using a specified force to establish a connection at the interface. These constraints only exist between different types of elements; they will be checked by compliance templates.
3) Accessibility constraints: Are similar to compliance contraints, but they consider the displacement of the components in all possible directions using a specified force to create a connection at the interface. These constraints exist between identical types of elements, and will be verified by accessibility templates.
4) Clearance constraints: Such constraints specify a "no-interference" area between two elements. Constraints do exist between different types of elements, and this type of constraint will be controlled by clearance templates. The principal objective of clearance templates is to control the "no-interference" zones or gaps between some subsystems during the assembly of two products. Similarly, clearance templates are able to control some functional constraints such as security. A security constraint could be the absence of a subsystem of type "A" at a distance x from a subsystem of type "B".

3.2 Templates' relation to part rigidity

The generation of each class of template reverts to a specific technique based on the level of "rigidity" of the involved parts. This study distinguishes between three different classes of parts: rigid, semi-rigid and flexible. The rigid class gathers parts that do not allow deformation; hence, for interface purposes, the Young's modulus of these parts is considered to be infinite and therefore allows no displacement during an assembly. The semi-rigid class gathers parts that allow a small deformation; for interface purposes, their Young's modulus is considered as finite -- allowing a limited displacement. The flexible class gathers parts with very low rigidity, such as an electric cable for which the range of displacement is the highest.

1) Contact templates are applied to rigid parts because their assembly is subjected to virtual conditions dictated by geometric dimensioning and tolerancing specifications, in line with existing work on virtual gages [26]. These are dynamic templates shared between partners and suppliers. Generated from part positioning specified by the interface control drawing that pertains to the ICD, contact templates control the validity of each connection from a single interface between two components Moreover, for standard parts such as a standard connector, the

template will focus on connector positioning. In the case of a custom design, the template will be more complex since it will model the part's geometry and position.

2) Compliance templates are applied to semi-rigid parts whose assembly is subjected to small distortions. This template allows verification of any problems with the assembly of different parts in the special cases where it is necessary to deform the part to create the connection. This method ensures that there is no interference with another part during assembly; for example, when a strain must be applied in order to make a connection to a hydraulic connector.

3) Accessibility templates are applied to flexible parts. Since they have some limited rigidity, these parts can be moved with almost no effort. This method creates a "swept" volume which represents the total space swept by a flexible part as it is moved around. A good example is an electric cable; if the "swept" volume overlaps with the connector of the other subsystem, then the accessibility is correct. In practice, actual rigidity will of course depend on the 'bundling' of the given cable into a harness, thus modifying the actual swept volume.

4) Clearance templates can be applied to parts with all types of rigidity. This template is generated through the creation of a shape around the part. Then, using this shape, clearance specifications can be checked by verifying that there are no interferences between the template and other systems or subsystems. This shape can represent numerous constraints, so that functional constraints can be translated into geometric constraints.

Table 1 : Mapping between templates and rigidities.

	Contact template	Compliance template	Accessibility template	Clearance template
Rigid part	✓			✓
Semi-rigid part		✓		✓
Flexible part			✓	✓

This table shows the different associations between part rigidity and templates. Only clearance templates can be associated with all part types.

3.3 Template implementation

The more practical portion of this research project explores how to create these templates in a typical CAD environment. Prototypes are developed using Catia since it is the most commonly used CAD system in the aeronautic industry.

Contact templates are composed from different models, each one independent and representing a single element from the interface (such as a connector). The positioning of this product is realized by a skeleton model representing the position of the parts in a common local origin (Figure 1). From there, it is possible to define some parameters for the dimensional and positional tolerances.

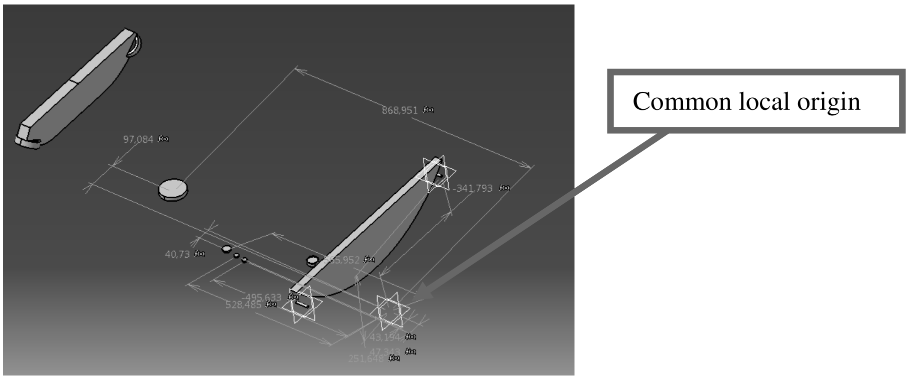

Figure 1 Contact template using a common local origin

The modeling effort is an important step because different parts are created without external references or contextual links from the digital model of a subsystem, thereby allowing the verification of template's positions.

In addition, it is possible to switch to different template configurations (in minimum or maximum material conditions). Switching configuration requires updating each model of the template. We can create a catalogue file that provides for the automatic generation of the other configuration of the template and thus creates one product for each configuration.

Compliance templates are created using the finite element analysis module of CAD software. The subsystem's node displacements are saved as a swept volume, and then inserted back into the product and checked against, using an interference function.

Accessibility templates are "swept" volumes. Some tools already exist in CAD software that allow the creation of a swept volume and it is possible to save the result in a file format which can later be integrated into the product. In its simplest form, this type of template can be applied to electric cables.

Clearance templates are created by generating a shape around the subsystem (or part) as an offset at a given distance determined by some gap interface specification. The resulting volume is then inserted in a geometrical set and used to check against interferences with other product parts.

In the next section we will show these implementations in an actual case.

4 Application case

Our application case is based on a realistic case: the assembly of a Pratt & Whitney PW305A engine on a Bombardier CRJ-X aircraft. In this example, we focus on the hydraulic tubing and its corresponding connector that has to be connected to the engine. This hydraulic tubing connector has two different rigidities: rigid for the connector and semi-rigid for the tube itself.

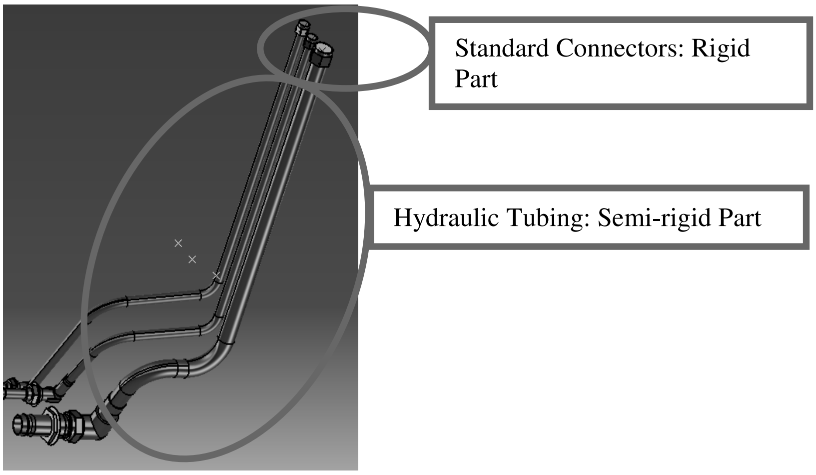

Figure 2 Hydraulic tubing and connectors

these hydraulic tubes with connectors, we apply three different templates: contact, compliance and clearance.

With the contact template, we know that the hydraulics connectors have standard fastening threads. Hence, to insure that the assembly respects the interface, the only control that needs to be to be performed is in regards to the position or localization of the templates, using the Catia Interference function to detect the interference (Figure 3) between the template (representing the engine side) and the hydraulic tubes that belong to the pylon.

For the compliance template, we specify one distance, one direction and one subsystem. To connect the hydraulic connector to another subsystem we have to deform the hydraulic tube. Figure 4 shows this displacement, and the Catia interference analysis allows the assembly to be verified with the other connector and ensures the absence of interference from other subsystems, such as tubes, during the displacement.

The clearance template can represent a security constraint between a hydraulic tube and another subsystem. The limit, in the present example, is 20 mm about the tube, where no other parts can lay. The surface offset allows the use of the interference function to verify the clearance constraint.

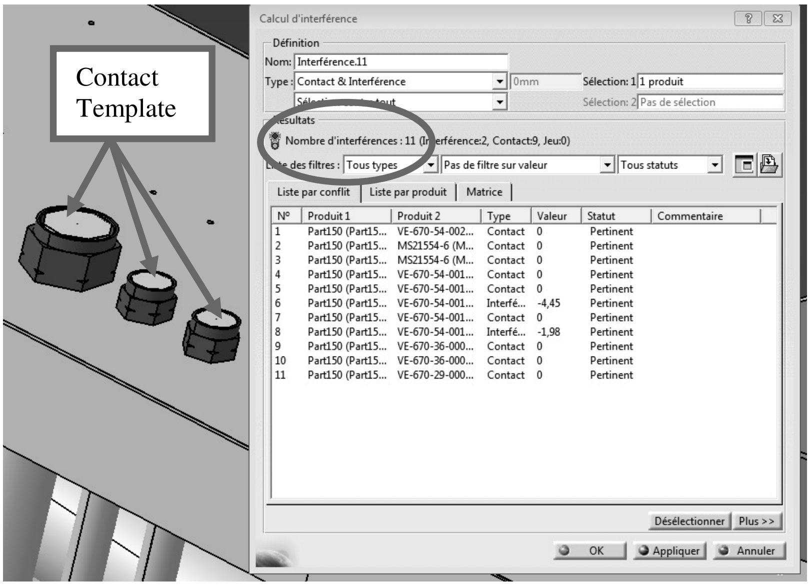

Figure 3 Contact templates on hydraulic connectors with interference module

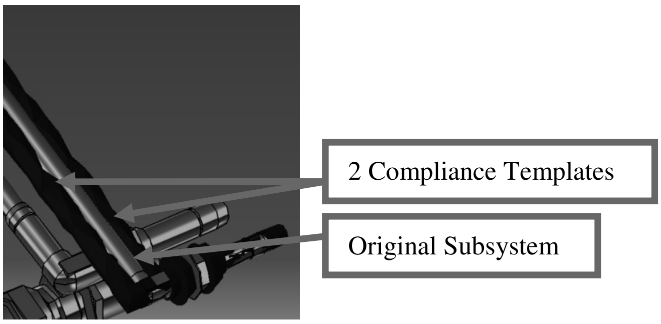

Figure 4 Compliance templates on hydraulic tube.

This application case illustrates the concepts developed in this research project. Templates are to be verified in this order (since it is useless to verify a contact if there is no accessibility): compliance or accessibility templates (depending on part rigidity) to verify if a connection could exist, followed by the contact template to check if there is a good connection between connectors. In the third and last step, the clearance template checks the other constraints. In any system, always verify the most complex interface according to Ullman's rules [12]. About the interoperability, the different templates could be exchange with neutral format like STEP or 3dxml files.

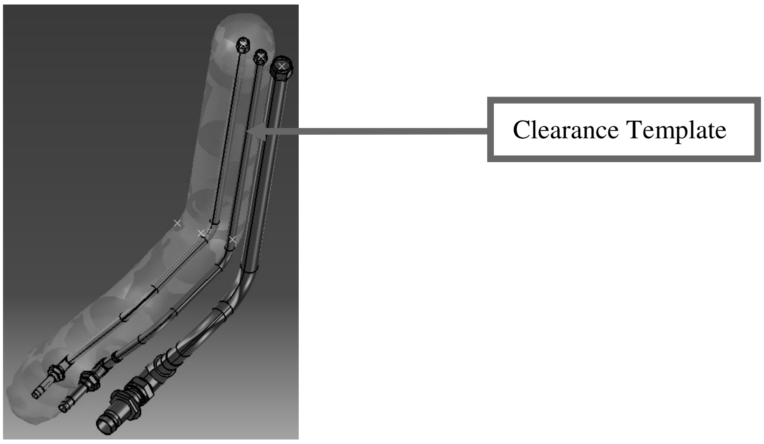

Figure 5 Clearance template on a hydraulic tube

5 Conclusion

Interface management and interface control documents are significant factors that can ensure efficient collaborative engineering in a PLM context. A template typology is proposed to systematically document specifications found in an ICD. Template implementation creates a numerical representation of the geometrical and functional constraints of an ICD, thereby allowing a link between an ICD CAD models. The different templates represent the different constraints from the ICD. The use of templates facilitates interface management by ensuring compliance to the ICD, thus preventing conflicts between subsystems. Moreover, interface control documents become clearer and easier to share, thanks to an explicit representation of constraints and requirements using geometrical templates. In addition, the proposed solution is integrated with designers' usual working environments._Indeed, the numeric representation can be used in the design phase of a new product development process when the product structure is determined. Hence, elements, interfaces and the links between these elements need to be define [20]. But the numeric representation can also be used during the verification phase of a new product development process when one needs to confirm with evidences that the specified constraints have been met by all collaborators and partners [20].

In the near future, this project research will develop an ICD management matrix capable of listing and classifying the different templates related to an interface between two subsystems. Rules to control the order of template creation and verification shall also be established in conjunction with that management matrix.

Acknowledgment

The research reported in this paper was undertaken as part of the "Collaborative Development for Product Life Cycle Management" (PLM2 CRIAQ) project. The authors are grateful for the financial support from the Natural Sciences and Engineering Research

Council of Canada (NSERC), the Consortium for Research and Innovation Aerospace in Quebec (CRIAQ), Pratt & Whitney Canada Corp., Bombardier Inc., CAE Inc., CMC Electronics Inc., and Rolls-Royce Canada Limited.

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Collaborative specification of virtual environments to support PLM activities

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Abstract: This paper proposes an environment to ease the integration of Virtual environment into PLM applications. The use of the newest technologies enabling virtual environments remains a hard process in the real world applications since every scenario leads to a new specific development. We investigate how to integrate PLM users, i.e. designers, manufacturing experts, or any other expert in the development of the virtual environment they expect. The virtual environment may embed any virtual reality technology. The development of the virtual environment becomes a User Centered Design activity where the Virtual Reality expert and PLM experts must collaborate to specify and build the appropriate environment. This paper discusses the main collaboration issues and focuses on the need for translating expert knowledge and know-how into visualization and interaction applications. Model Driven Engineering is proposed to support this translation.

Keyword: Collaboration, Preparation of a virtual environment, Model Driven Engineering, PLM

1 Introduction

PLM relates to technologies, tools and methods to organize and to design the life cycle of products. Current tools mainly focus on the management of product information and support shared access to these information. However deeper support of activities could help to improve PLM uses: the integration of multidisciplinary simulation for complex product behaviors inside virtual environment may be such a case. As described by Xiao and al. [4], PLM does not fully support users with a complete and consistent access to complex product virtual prototype [4]. Demands for the integration of a high number of knowledge entities in PLM systems are increasing. Collaboration for the dynamic integration of new concepts and experts that are used along the product life cycle are tremendous trends [1], [2]. Indeed PLM tools should provide a better digital cooperative workspace and should improve communication among experts in different fields. A new generation of software tools is expected to simplify database access, information, visualization and interaction with information and other experts [3]. Due to PLM complexity, new technologies and methods are required to enhance the understanding of activities and their interrelation through product lifecycle.

We are convinced that PLM could take advantage of the newest Virtual Reality (VR) technologies to improve interactions. In this communication, and for the sake of clarity, we'll consider that VR encompass the field of Augmented Reality which allows superimposing digital representations with real world views. VR technology can provide the access to digital archives easier and make it more attractive; it supports real 3D visualization and perception and a more natural user interaction with 3D objects: users can navigate in the 3D environment simply through visual, audio and other sensorial devices; it allows users to not only visualize information but also to interact directly and naturally with the data in three dimensions [7]. Today, the preparation of a virtual environment is still a specialized, time consuming and expensive process. Most techniques and software tools require considerable knowledge about VR technology, programming skills and/or knowledge about computer science languages. This limits the participation of non VR-experts in the design and development of a virtual environment [5], [6].

The improvement of PLM connection to virtual reality environments is based on three key points:

1. The right balance between 2D and 3D interactions: PLM is a professional activity where efficiency is the priority. We must not propose 3D virtual environments just for fun and determine when 3D is appropriate and when 2D remains a good interface. Most Virtual Reality techniques allow working into a 3D virtual world and thus require 3D models for visualization. Usually product digital mockups are already modeled in 3D within CAD system and access to 3D information is not anymore a real difficulty. However the product is not alone and the creation of 3D environments will require the definition in 3D of the product environment. For instance, recycling expert who has to design the recycling process deciding what will be disassembled, remanufactured, destroyed or recycled, does not work currently on the CAD model. Instead, they manipulate the physical product to disassemble it and check the potential difficulties. We can assume that such an expertise would take a great benefit from 3D virtual environments.

2. Collaboration improvement: PLM requires the collaboration of many experts all along the product life cycle. Collaborators must negotiate the technical decisions about the product definitions, every related manufacturing and usage processes up to the recycling processes. The most current approach for this interaction is to organize meeting (project review meetings, videoconferencing, etc) where expert show their own results and constraints and then try to solve potential conflicts [8]. There is no complete formalization of this collaboration step and the medium used are often based on simple slide show. The main point remains the translation of every complex expertise onto communication supports. This concept must be generalized within Virtual Reality as new media for communication in collaborative projects. However, it will be expected to master the translation of the user need into an efficient virtual environment to seek communication purpose.

3. To develop new paradigms and metaphors to ease the understanding of PLM complexity: If PLM stands for Product Life Management, the core issue remains

the management of a complex set of information and of human interactions. A good direction of investigation would be to take benefit of new dimensions of interaction offered by VR technologies to better master the PLM complexity of data access.

Academic and commercial software are developed to support VR environment design. However, to build an application dedicated to the expert analysis will be a unique and complex computer science development that must be resumed for every use case and for every type of device. Conventional representations of product through its life cycle are not optimized for VR environment. Also there is a gap between domain concepts and VR model. Finally translation of requested scenario from the application domain into virtual environment remains an issue that must be undertaken. Automatic or semi-automatic model transformations will help to increase portability and development efficiency, which can increase PLM usage of the corresponding technologies. In this paper we try to define how Model Driven Engineering (MDE) may support this expected translation.

2 Architecture for constructing a virtual environment dedicated to PLM

Expert involved in PLM are highly specialized and have specific tools to support their own activity. We assume that they belong to an activity domain. Every domain relates to a specific ontology: a set of concepts that can be organized to describe the domain activity. Unfortunately PLM was not able to build a unified and unique ontology holistic enough to take in charge every domain. Then the management of semantic transformation from a domain to the VR environment is a fundamental key point for our purpose. We propose a model driven based architecture (Figure 1) to accelerate and to improve VR scenario creation from several aspects. This architecture must support 1 – collaborative work between different experts (a VR expert and several domains experts), 2 - Fill the gap between several concepts in application domains and VR implementation concept. This work is done by translation and mapping domain concept to VR concept, 3 - Direct contribution of domain expert in implementation of VR scenario.

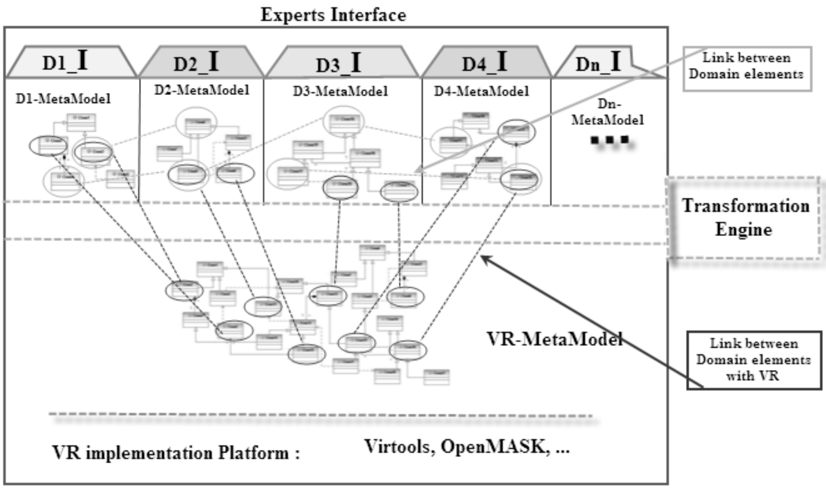

Figure 1 The Proposed Architecture.

The collaboration between the VR expert and the different domain experts unfold according to this process:

1) To determine all involved domains for the expected PLM activity.

2) To identify the ontology associated with each domain and also to determine tools and methods that are used by the corresponding experts.

3) To formalize ontology of each domain through various models and computer tools. We must identify the models which will be tangible enough for the undertaken use cases. The meta-model of selected tool for each domain has to be defined.

4) To build crossed reference between the different domain models when this correspondence are not explicit. This link creation is done by collaborative work between different experts and knowledge sharing.

5) A mapping is defined through mapping rules. After mapping the source model the resulting target model is not fully complete and must be finalized by a VR expert. However, in some cases translation can be automated [9], [10]. In our proposed architecture, domain models are source models and VR model is target model. Several domains may be involved for providing different part of VR model for realizing scenario.

6) A transformation engine is created. This transformation engine is the main output of the current process. It is the core element of this architecture. It provides automatic and semi automatic transformations by using transformation rules defined by experts in collaborative way. These transformations will be applied to real models to create a virtual environment.

This process is classical within Model Driven Engineering. A specific attention here must be applied to enable a dynamic application of this process. We will next evaluate the feasibility of the proposal.

3 Evaluating proposed architecture through a use case

To evaluate the capacity of MDE to support PLM domains concepts translation to VR concepts, we consider a case study that is related to manufacturing phase. Virtual reality is viewed as a tool for simulating manufacturing systems. Virtual reality not only provides an environment for visualization in the three-dimensional space but also to interact with the objects to improve decision making from both qualitative and quantitative perspectives [11], [12]. Interaction will help the integration of non planned events. In this case the goal of scenario is to achieve a real time simulation of a production line and it's rendering into a virtual world to evaluate its capacity before its physical implementation. In this case experts want to map the real world concepts of this project into a virtual environment. In this type of scenario, the main part of concepts, information, data and knowledge required for implementing the scenario already exist in several engineering perspectives stored in the PLM systems. Different domain concept and engineering models are involved to model the scenario. Also several softwares exist to model different engineering concepts of the production line. To create a virtual reality environment many of these concepts are used for defining the objects and their property (3D modeling, location, orientation, behaviors …). On the other side, several software tools exist for VR implementation.

The use case concerns the design of a shop floor. A shop floor is a dynamic environment where unexpected events occur, and impose changes to the planned activities. Virtual reality could be a useful tool to improve the understanding of the plans and to support interdisciplinary discussions. A mapping process between Shop Floor Concepts to VR; will take several models as input data (the sources) and will produce one output model (the target model i.e. the VR Model) which will be used to achieve the final analysis.

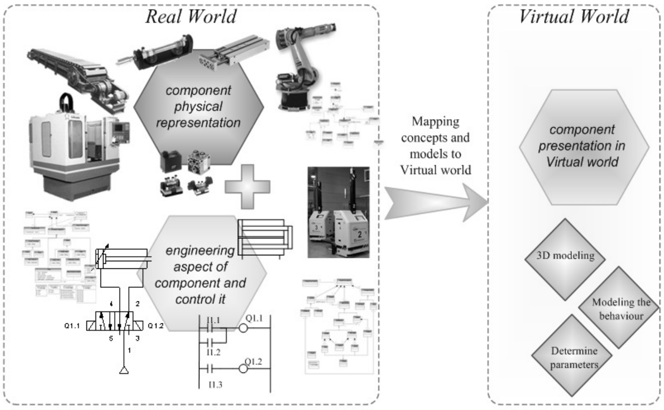

Figure 2 Shop Floor Concepts and Models_ Mapping and Transferring to VR

To illustrate the process, we selected several models and concepts that exist in a shop floor (Figure 2) and we determined the process of mapping. Shop floor resource, Programmable Logic Controllers (PLC) and pneumatic concepts were selected for this first evaluation, but there are many other concepts that are required to map a real engineering use case into a virtual reality environment. Determining other concepts and completion mapping process as a dynamic process to integrate them on the fly of normal PLM activities is an objective for future work.

3.1 Sources and Target Concepts and Meta-Models

To map the concept of domains models onto a Virtual Reality model, we must identify the relationship between different models and consequently meta-modeling. A meta-model is a collection of concepts and their relationships. During the meta-modeling process, the basic step is to determine the modeling paradigm that contains all of the syntactic, semantic, and other information of the domain to be modeled. Generic modeling, i.e., meta-modeling, is the mapping of specification concepts onto entities, relations, and attributes of a specific domain [13]. The meta-models must be defined by using a technique of meta-modeling (i.e. languages for creating meta-models). In the following subsections meta-models of target and sources are presented in UML format (Unified Modeling Language).

3.1.1 Target meta-model: Virtual Reality Meta-Model

In the mapping process the target model will be the VR model. This Meta-Model (Figure 3_VR meta-model) is created to describe the major component that relates to domain of VR-Scenario, to help mapping process from domain models to VR-model. In other words we ignore the part of VR-meta-model that concerned architecture of VR-software for implementing scenario. But in real case, a complete model of VR has to be considered to determine the detail of model required for implementation. Although several academic or commercial systems supporting VR models exist, there is no specific standard. As a consequence, a generic work must attempt to generalize the meta-models of existing VR solutions. By analyzing the existing systems we identified the main usual concepts and components of VR-meta-model. :

- *Virtual world:* The environment where virtual objects are located. Virtual world can have some attribute of real world for example: lights and gravity, etc. changing viewpoints and navigation on this world is possible for user through input and output devices.
- *Objects:* The object refers to entities that have graphical representation in scene. The attributes of object that have to be considered and represented in the virtual world, can be categorized in two type: *Attributes of object that influenced in graphical representation* (shape and geometrical attribute, color, position, orientation,…) and *Attributes of object that influenced in object behaviour* (material, components,…). Some attributes of some objects will influenced on both aspects: material type impact the behavioral aspect: it influences the reactions of object in case of collision and, from a graphical representation point of view; it influences the light reflection of object in case of real rendering. However, scenario requirement (application, level of detail, level of immersion…) will determine needed attributes for each object.
- *Event:* An event is a single moment in time when something happens. The event triggers an action, and/or behaviour.
- *Behaviours:* any event affecting objects are related to a simulated behaviors. The objects must be associated to behaviors. In VR-software and implementation view, behaviors are program scripts that are associated to objects. The name behavior is a quite generic concept. For instance, in Virtools [14] there are three types of behaviors: Building Blocks, Behavior Graphs and Scripts. In our meta-model according to domain expert's view we divided behaviors between those which are dependent to user action or to other object and those which are intrinsic to an object, i.e. independent to other object.

3.1.2 Shop-floor Meta-Model

Every expertise use also specific models that can be formalised in a corresponding meta- model. Here we extracted the shop floor meta-model (Figure 3_ shop floor meta-model) from the model proposed in [15]. It integrates a control system, responsible for the coordination of the manufacturing physical and information flow [15]. Every system or machine is supposed to have a controller built on a specific technology: pneumatic, hydraulic, electrical, PLC and electronic controllers or a combination of these technologies [16]. The shop floor control system, associates with the shop floor resource, imposes an adaptable hierarchy over other intelligent agent controllers and keeps track of the shop floor status. Such an adaptive hierarchy imposes product priorities, changes of environment and copes with internal disturbances by reassigning other objects [15].

Here we do not redefine every meta-model. We thus use a meta-model (Figure 3_ pneumatic meta-model) for pneumatic systems [17], [18] and PLC meta-models (Figure 3_ PLC meta-model) [19]. Indeed here, existing standards could be taken as reference for the definition of meta-models.

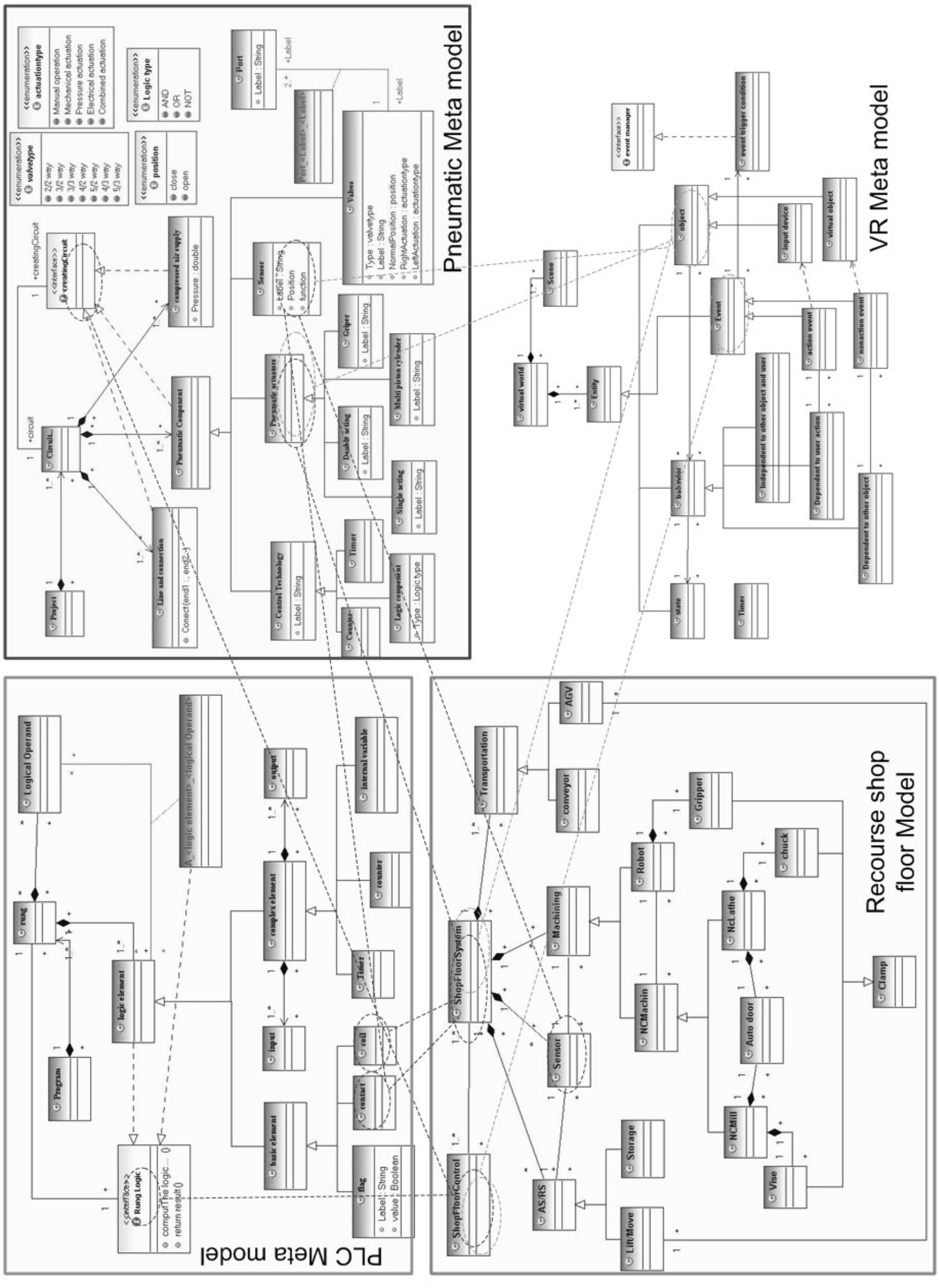

Figure 3 Sources and Target Meta-models and indicating some of existing links between them

Various diagram techniques have been developed to represent the logical elements and their relationships in a given logic control system. These diagrams should stand for instantiation of the proposed meta-model. For our demonstration, we used Ladder Logic Diagram for logic control system [16].

3.2 Mapping Process

In previous sections, the Meta-Model and concepts of source models (PLC, Pneumatic and shop floor) and target model (VR) were determined. The mapping process determines how a domain concept should be represented in the virtual environment. Rules as "name and type matching" simplify the process of model comparison. This mapping is based on the syntax of a modeling language. In complicated situations, two models can be syntactically different but semantically equivalent [13].

However model elements may have no explicit reference to each other, then the relationships between the source Meta-Models must be manually identified. Complex appropriate patterns and transformation rules must be defined to translate the entire source into the target model. One or more elements of the source model can be mapped to elements of the target model only after additional decisions have been made. Consequently, such a mapping is ambiguous, which implies that a selection among several alternative mappings must be performed [13]. It is also a collaborative work where the experts from PLM business knowledge and Virtual Reality must cooperate to define the right mapping. A model and its translations are usually connected using various kinds of relationships. These relationships can be formal or informal, complex or simple:

- Equal concepts or attributes (basic case): Components and equipments in shop floor and Pneumatic component can be equivalent to object in VR model. Each VR object attributes (graphical representation, position, orientation, initial state, three types of behavior, and condition for triggering the object behaviors …) have to be determined. Some of these attributes can be captured from mapping concept, but additional attributes have to be determined by domains experts.
- Transformed concepts or attributes (general case): in this case a set of objects and concepts from the PLM world have to be transferred to the properties or behaviour of some virtual reality objects.

A mapping function [20] is a collection of transformation rules. Mapping functions enable the construction of target models that are consistent with the target meta-model [9]. In some cases the rules are not automated and the link between elements of different domain models must be identified by hand on a collaborative way.

Each component posses its own behavior, so the behaviors of each component that was selected to be mapped as an object in VR have to be determined. The behavior is defined independently of how the behavior will be triggered. This improves re-usability and enhances flexibility. The control of these components has been done by PLC, pneumatic concepts and model mapping.

3.3 Example instantiation

The meta-models were instantiated to describe a Hot forging Production Line (Figure 4, 5). The main set of components and equipments that are used include:{ 2 robot arms, 2 conveyors, 2 cylinders (one for barrier, another for cutting), counter for counting the number of cutting operation, 3 buttons (start, stop and restart commands) }.

The control of the behaviour has been ensured by mapping PLC model (See Figure 4: PLC model of Case Study _Hot forging production line). This example demonstrates the capacity to use efficiently expert models to create an animated 3D scene (Figure 5) that can be used as the model for a virtual reality environment. Final user will enter the virtual world and experience more direct and natural interactions with the simulated production line.

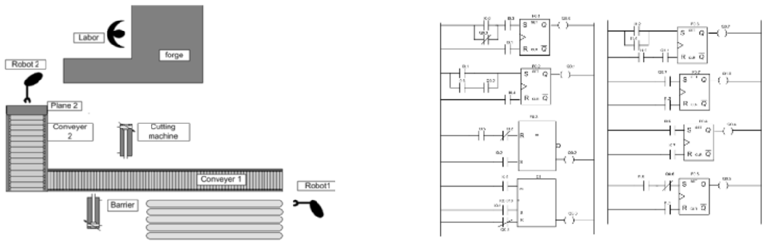

Figure 4 PLC model and plan model of Case study (Hot forging production line)

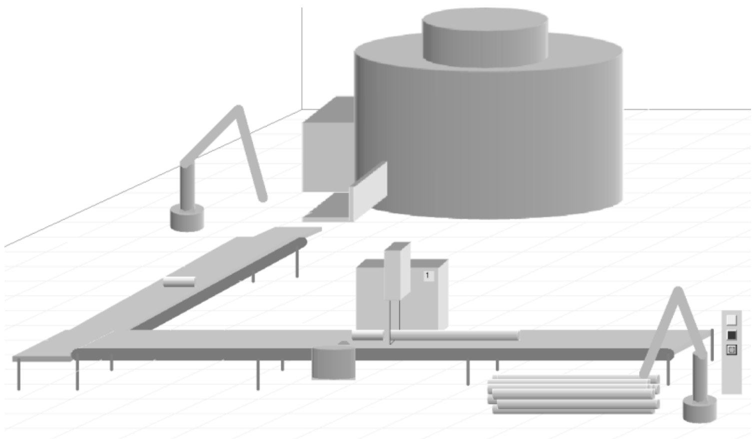

Figure 5 VR model of Case study (Hot forging production line)

4 Conclusion

Visualization and interaction technology is a major opportunity to improve intuitiveness inside PLM activity. It will support a better understanding and will enhance multidisciplinary collaboration and decision making management. We also show that this kind of process rely on the data and information stored in a PLM system, but also provide new environments that can be put available and disseminated through the same PLM system. However there are still gaps between PLM component and VR: (1) Translation perspective from PLM world to VR world, (2) 3D model retrieval from PLM concepts to build VR characteristics, (3) Collaboration for dynamic definition of VR behaviors representing expert's needs. This paper proposed a generic architecture taking benefits of MDE concepts to ensure the expected translation but a major extension of this work will be to assist collaboration of experts in defining the behaviour of environment.

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PLM benefits for networked SMEs

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Abstract: PLM is universally recognized as a valid strategy to reduce time to market, increase process efficiency and reduce lifecycle cost. Despite the importance for industry to prove these emphasized competitive advantages, PLM achievable benefits still remain intangible. Their measurement is particularly difficult in case of networked enterprises where each of them is characterized by different organization, personnel skill, level of computerization, etc. Moving forward, this paper presents the results of a long-term study carried out on several Italian manufacturing companies, mainly small and medium sized, about the quantification of PLM benefits for collaboration. A structured approach is developed to assess the quality of a collaborative PLM implementation and its impact on real processes. Finally the cost-reduction achieved by the new system has been estimated on the basis of the companies' hour cost. Results are remarkable and make evidence of great time and cost saving. This study shows a reliable experience on how PLM can successfully support companies to improve collaboration and hence to face the current economic crisis.

Keywords: PLM benefits, industrial experience, CPD (Collaborative Product Development), extended enterprise.

1 Introduction

The present study aims at exploring the advantages connected to PLM tools implementation in Collaborative Product Development (CPD). It fits the modern industrial scenario, where the increasing global competitiveness and high quality standards force industry to adopt such systems but they are often not able to understand the achievable benefits.

In the last two decades, Information and Communication Technology (ICT) have been used to support product development processes, from CAD-based tools to knowledge-based systems, virtual prototyping techniques and other advanced digital technologies, until the realization of complex software platforms to store, retrieve and reused product data (EDM, PDM, etc.). PLM (Product Lifecycle Management) represents the highest-level class of such tools because it is firstly an approach to integrate all process stages and relative supporting technologies [1]. More recently it moves towards mutual and shared applications since industry has assumed a more collaborative character to face modern market challenges. The final scope is to support the so-called CPD, which requires cooperation of different disciplines and knowledge-data sharing to enhance product quality and shorten design process [2]. Furthermore, the new collaborative asset increasingly involves Small and Medium Enterprises (SMEs) as suppliers, consultants, designers, or other outer resource useful to produce the final product. As a consequence, small enterprises add complexity to product lifecycle management as they bring their special needs inside the extended scenario: flexibility, agility, lean reconfiguration to different process-products, easy to use and low-cost.

To support multi-company collaboration, PLM approach has to be modular and adopt an open architecture where its modules can be custom-made according to the needs of different actors. This is the best way to realize effective CDP and perform high-quality activities among numerous project partners in respect of specific product and process requirements [3].

The main benefits of achieving an effective CPD for companies are:

- Creating collaborative virtual spaces to share data and knowledge;
- Securing their corporate design data while facilitating access by authorized personnel;
- Increasing design reuse, facilitated by a powerful and flexible search capability;
- Streamlining their engineering process with remote collaborative design review and release workflows for an effective change management;
- Error reduction through more effective collaboration between departments and the elimination of mistake manual handoffs to manufacturing;
- Rapid deployment of full-featured product data management solutions;
- Reducing product cost and time to market, thanks to shorter product lifecycles.

However the quantification of the achieved benefits in tangible terms is crucial. Industrial surveys often highlight potential profits or indicate the percentage efficiency increase without giving objective evaluation. Furthermore, benefits are usually analyzed in respect of the single company dimension and without considering the whole supply chain neither assessing the impact of the whole industrial chain.

This paper investigates the requirements of a complex supply chain made up of 13 companies (12 SMEs and 1 Large Enterprise as the leader company) whose final products are wellness products and systems. Daily work has been supported by two different ICT systems over the years: a traditional PDM system and then a collaborative PLM platform, consisting of three modules: a PLM platform for technical and commercial data management (provided with several ad-hoc customizations), a web portal for technical collaboration, and a CRM-based product configuration tool. The present work aims to estimate the benefits of the two systems on the basis of a set of key processes and relative performance indicators measuring system usage, process performances and users satisfaction. Instead of other studies about PLM assessment [4, 5], the actual research proposes two main novelties: it allows quantifying benefits in terms of time and cost savings, and it considers the impact on the whole industrial chain, not only on the leader company.

2 PLM applications for SMEs in the extended enterprise

The PLM concept has been developed in the last two decades due to the widespread of ICT and is based by definition on "*integrated, information-driven approach comprised of people, processes/practices, and technology, to all aspects of a product's life*" [1]. It is focused on people integration and cooperation across the entire product lifecycle and it mainly aims to shorten production time, enhance the product quality, and improve innovation. In recent years, collaboration has become crucial for competitiveness and sharing data and knowledge among all participants in product development is fundamental to be successful. This approach, called CPD (Collaborative Product Development) fosters a new business model based on continuous interactions among multidisciplinary teams, whose competences, skill and effort converge to realize a high-quality products and smart services. Collaboration results particularly critical during product development stages where the shared product understanding has to be optimized in a distributed, heterogeneous and dynamic environment [6]. In this context different expertise, individual knowledge and personal background of actors participating to product development require the creation of a common workspace and the adoption of a common language to share design contents. From an operational point of view, collaboration in design teams implies the simultaneous evaluation of the design outcomes from conflicting perspectives (market penetration, customer satisfaction, global usability, perceived quality), the integration of specific solutions into a whole and coherent product design and, finally, the management of all product data. In last years, traditional PLM definition evolves towards *"a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, and spanning from product concept to end of life - integrating people, processes, business systems, and information"* [7]. However, PLM applications still remain anchored to traditional ideas: PLM vendors offer more functional modules enabling additional functions (e.g. on-line and off-line communication, remote messaging, shared calendars, project management tools, etc.), but they do not have changed they way users use them. So practically, the users' approach remains the same.

In order to face the mentioned problems, PLM approach should change: it has to be modular, flexible and customizable on the basis of specific users' needs, easy integrated with other applications (also external ones) and interoperable in order to really support collaboration and the requirements of different actors [3]. Besides collaboration, another important aspect to consider regards with the dimension of companies adopting a PLM strategy. In case of small and often micro-sized enterprises PLM implementation is not a trivial task. Instead of Large Enterprises, they have limited resources, both human and financial, no high-level skill, scarcely role-playing, etc. Different needs emerge and PLM tools have to be adapted with great effort from both the developers and the users. This problem becomes more complex in case of networked SMEs. The multi-sized networked collaboration gets the following research issue to emerge:

- the importance of integrating multiple independent organizations (differently sized and equipped) by offering a common space for interaction;
- the relevance of knowledge and data sharing in conflicting teamwork made up of multifaceted competencies (marketing, design, engineering, manufacturing, etc.);
- the need to address and flexible CPD, that can change configuration depending to project tasks and team composition.

Nowadays, in the scenario of CPD supporting tools three main classes of applications can be distinguished:

a) Authoring tools used in a combined way to satisfy specific business requirements (i.e. CAx, PDM and simulation tools). The market is characterised by numerous ICT players that provide solutions to support all different product development stages (e.g. Autodesk, Dassault Systèmes, PTC, SIEMENS, etc.). This class is mainly represented by stand-alone tools for managing different aspects of product development: from ERP system for managing financial records to Supply Chain Management (SCM) system for managing supplier support, until Product Data Management (PDM) system for managing product data and workflows. However, the provided functionalities are almost traditional and not suited for multi-company collaboration;

b) CPDm (Collaborative Product Definition management) tools, those integrate PLM systems with additional modules dedicated to collaboration, visualization, vaulting, or sharing of product-related information. This class is mainly characterized by vendors coming from ERP systems world (such as Oracle, SAP, etc.) and by many small-sized enterprises that developed customized PLM applications. They are all based on the integration of different PLM subsystems and tools or their enhancement by customized applications in order to create collaborative and competitive business environments. These tools allow performing some collaborating activities along the product development process even if the level of integration and interaction among teamwork participants is limited and high-collaborative activities usually suffer of lack of support;

c) Computer Supported Cooperative Work (CSCW) tools comprehend a wide range of technologies to support team members in interdisciplinary work across the involved design and supply-chain. Functionalities can vary from data visualization, to 3D models representation, real-time rendering, product models mark-up, audio-video communication support, Web 2.0 services, etc. [8]. The more advanced ones also allow carrying out basic modelling activities The main examples and their features are well described by a recent review work [9]. Some tools also realize virtual design spaces to enhance the interaction with products and people by involving multiple sensorial channels and acting at an emotional level [10-12] or realize Networked VR-based environments (NVEs) to create distributed workspaces to remote virtual mock-ups [13]. This class is probably the most promising to address teamwork collaboration needs but applications are still limited to Academia and not mature for secure industrial use. They usually lack of experimentation, validation and also follow-up optimization.

From a technological point of view, the first two classes of tools are mature for industrial applications and used also by SMEs, but they are not able to effectively support CPD in complex networks. They are not able to manage geographically distributed teams as required by the virtual enterprise paradigm. Contrariwise, the CSCW tools promise to be more effective in supporting collaboration but, as already highlighted, they suffer from system interoperability and reliability problems, difficulties of integration with real industrial design context, complexity of use [14]. By recent industrial surveys concerning the level of technological exploitation [15], we demonstrated that some open issues still limit their application in real industrial design contexts: the high cost, the low usability in terms of users satisfaction, the difficulty to identify the proper technology for the specific collaboration needs, the low sense of presence that influences a scarce engagement among virtual teamwork participants. From a methodological point of view, the evaluation of the collaborative advantages is still an open issue. Although a lot of attention has been focused in recent years on the comparison of different PLM solutions, evaluations usually scarcely consider the specific industrial context and the networking benefits. Benchmarking allows companies to determine which functionalities should be implemented to address end-user needs [16]. Numerous industrial surveys have been presented to provide a good overview of the PLM market, tools usage, level of PLM integration or decision-making drivers [17, 4, 5]. However, they often analyze the advantages in terms of incremented process efficiency and percentage increase without providing tangible data in terms of achieved process time and cost reduction. Furthermore, collaborative processes are not analyzed in details by comparing the development in pre-PLM and post-PLM situations.

As a consequence some issues still remain unresolved. They mainly refer to the evaluation of PLM performance and benefits, as follows:

- How to arrange a suitable PLM application for industrial complex network? Which is the right trade-off among the existing technologies to guarantee reliability in use and proper collaboration support at the same time?
- How to evaluate the PLM benefits for extended enterprises and how to objectively quantify them? Which is the proper method to carry out a valuable analysis? Which are the process indicators to consider?
- How to assess the level of PLM fitting to collaboration requirements? Which are the available functionalities most suited for cooperative work? How are they combined for a specific CPD context? How should the business process reengineering be carried out to implement a PLM solution and achieve a system optimization?

The final aim of this research work is to address this question by proposing a feasible technological trade-off and proving the achieved benefits.

3 PLM evaluation in SMEs: the method

Starting from the Rubin's model [18] to assess system performance, a structured protocol has been developed. It allows the scheduling of experimental sessions in an appropriate way according to the analysis objectives, the definition of proper metrics of assessment and the identification of suitable methods for processes' investigation and data collection. Concerning the definition of tasks and metrics, we consider also some previous studies by Grieves suggesting how to measure business processes and their outcomes for PLM systems [1]. The adopted protocol consists of the following stages:

1) **Definition of the testing objective** that is the measurement of benefits connected with the use of collaborative PLM systems to support SMEs networking. The evaluation has to be useful to companies in determining the real benefits of their PLM investments and assessing if their PLM efforts are paying off. The analysis becomes relevant only if its results are compared with ones achieved in case of traditional supporting technologies.
2) **Choice of sample users for the investigation**. In case of SMEs networking, sample users belong both to the design and supply chain and to the leader company. Sample teams are arranged around as follows: 20% persons from micro companies, 50% persons from medium sized enterprises and 30% persons from the leader company. In case of individual use of the exploiting technologies, the number of selected sample users is chosen according to the same percentages. This enables a balance of the achieved results that are not too much influenced by the skill and expertise of the leader company staff.
3) **Definition of a set of key processes to be analysed**. They are strategic for the leader company to achieve a high CPD performance. These processes imply numerous and continuously changing tasks to be carried out by the companies according to the

project they are involved. The measurement is applied to these tasks but the whole performance is referred to the key processes.

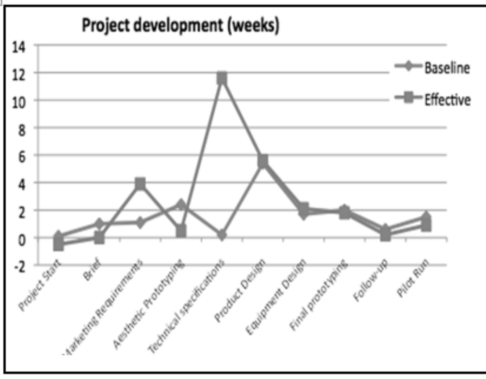
4) **Identification of a set of metrics as qualitative and quantitative estimate of key processes performance**. Metrics are defined in order to measure PLM achievable benefits. They do not refer to the effort for system implementation (i.e. employed human resources and costs of investment). Metrics are arranged into three classes: a) satisfaction in use (subjective measurement of system usability), b) process efficiency (objective measurement of time saving) and c) quality of system use (objective measurement of end users' practice during system use). The first aims at evaluating users response about the comfort in use, the quality of the provided support, the perceived utility according to individual and collective task goals and technical performance. The second measures the duration of the activities undertaken by sample users to accomplish the tasks of a specific key process. Times are distinguished into "actual time of execution" that is the effective time spent by the user to complete the specific process activities, and "process lead time" that refers to the entire process duration. Duration can be represented as the time saving in respect with the performance of other PLM system or supporting communication technology. Finally, the third is an indicator of the quality of usage. It is measured by collecting the number of users' accesses, of web pages visits, the access duration and the number and typologies of shared and exchanged data.
5) **Collection of objective data about the system performance** (metrics b) and c)). In particular data for metric b) can be collected by adopting two investigation techniques that are Diary Study and Video Interaction Analysis (VIA). Diary Study is widely adopted to elicit information from design processes by a series of qualitative and quantitative data retrieved by the observer during users' work (date, project phase, completed activities, number of physical prototypes, number and type of actors). VIA is commonly used as an interdisciplinary method for empirical investigation of human beings. VIA generally requires a video camera capturing dynamics of teamwork and complexity of interactions. Both VIA and Diary Study allow to collect data for single project tasks. In parallel it is possible to analyse the reports of the systems generally adopted for the financial balance and project management. A specific logging SW to monitor and register PLM tools pages access is used to collect data for metric c).
6) **Collection of subjective data** by interviewing employees and managers directly involved in the specific process and by submitting to them a post-hoc questionnaire aiming at collecting judgements expressed into the 5-point Likert scale.

4 The industrial case study

4.1 Dynamics of SMEs network collaboration

The proposed study has been experimented into an Italian supply chain made up of 12 SMEs and 1 large-sized company. The whole study lasted about three years. All analyzed companies belong to the design and supply chain of a large-sized Italian company that designs and manufactures sanitary products for wellness and health (e.g. multifunctional bathtubs, saunas, showers and hydro-spas). The leader company drives all chain's processes: it defines the process targets, the product development goals, it moderates collective activities and coordinates the individual ones, it checks the correspondence between specifications and achieved solutions, it plans the manufacturing schedule, etc. Partners are: styling studios, marketing consultants, financial consultants, external designers, prototyping and certification studios, suppliers of mechanical and electronic components, suppliers of manufacturing processes, toolmakers, experts in graphics and rendering, research centers and Universities. They assume different roles in the CPD process. They undertake different activities: to realize high quality renders and photorealistic images for preliminary decision-making, to create drawings and 3D models for detail and embodiment design, to realize some product components or production equipment, to de-feature CAD models for technical manuals and supporting data sheets, to prototype the physical mock-ups of the design solutions for testing sessions, to perform specific simulations and analysis for technical feasibility, etc.

From the analysis, collaboration results particularly intense during the feasibility stages, where the project requirements need to be translated into product functionalities and features. Figure 1 shows the average time values of numerous projects involving SMEs: for each process phase (feasibility and development), the scheduled timing (baseline) and the effective timing (effective) are compared. It shows that the most critical stages are those where the effective duration exceeds the scheduled one by the leader company. In particular, the feasibility analysis is the most risky: delays have been detected in the definition of marketing requirements and technical specifications, where numerous unexpected events (e.g. priority change, target market analysis, competitors analysis, changes in the design team competences or responsibilities, etc.) occur and cause huge delays in the project advance.



	FEASIBILITY				
Project stage	*Project Start*	*Brief*	*Marketing Requir.*	*Aesthetic Prot.*	*Technical spec.*
Baseline	0,1	1	1,1	2,4	0,2
Effective	-0,5	0	3,9	0,5	11,6
GAP	-0,6	-1	2,8	-1,9	11,3
GAP %	166,90%				

	DEVELOPMENT				
Project stage	*Product Design*	*Equipment Design*	*Final prot.*	*Follow-up*	*Pilot Run*
Baseline	5,4	1,7	2	0,6	1,5
Effective	5,6	2,1	1,8	0,2	0,9
GAP	0,2	0,5	-0,2	-0,4	-0,6
GAP %	-4,70%				

Figure 1 Results of the analysis of numerous real collaborative projects. At left, the graph presents the average duration of project stages (baseline and effective). At right, the table shows the investigation of two main critical phases.

The feasibility stage has been deeply analyzed. The main problems identified regard the exchange of data among project partners and the knowledge sharing. Common data sharing modalities have been also listed in the table of Figure 2 where data, exploited communication channels, roles of involved persons and frequency of interactions are reported. The histogram presents the results of several interviews submitted to project managers about possible improvements to overcome collaboration problems. This study suggests that CAD models and commercial documents need to be shared and widespread in an easier way. On the other hand, the use of physical prototypes could be reduced, also in virtue of the high costs of realization and transportation. These results appear to be quite representative of the Italian industrial scenario, characterized by numerous and small enterprises, interacting with larger ones.

DATA	SHARING MODALITY	SUPPORTING TOOL	ROLES INVOLVED	FREQ.
Technical data sheets and manuals	Electronic (.doc .xls .pdf .ppt)	E-mail, fax, meeting (also VR Labs), FTP	Technical dept., Marketing Dept., Sales Dept., Labs	Daily, weekly
CAD models and files	Electronic (.igs .stp .dwg .dxf .jpg .png .zip)	E-mail, currier, physical meeting, DVD	Technical dept., R&D Dept., Industrial Eng.	Daily, weekly
Commercial-Marketing data	Electronic (.doc .xls .pdf)	E-mail, mail, fax	Marketing Dept., Sales Dept., Adm. Dept., Supply Dept.	Week ly
Physical prototypes	Rapid prototypes, foam models	Mail, physical meetings	Technical dept., R&D Dept., Labs	Month ly

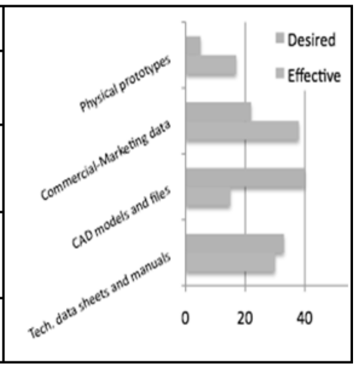


Figure 2 Data sharing modalities: effective and desired

4.2 Experimental conditions

Notwithstanding the inner differences among the 12 involved companies in terms of dimension, skill, organization, undertaken activities and process goals, all testing participants adopt in general the same technologies for communication, data management and process control. They have progressively improved their computerization level to adapt to the leader company needs and adopted technologies. Their aim is to strengthen synergies and to keep their roles firm in the design and supply chain.

Business cooperation and collaboration in product development have evolved over the years: from a preliminary stage where communication was mainly based on traditional supporting technologies (e.g. fax, e-mails, ftp servers, etc.), to an intermediate one where enterprises were forced to interface with the PDM system adopted by the leader company, till the current one where a custom PLM system has been implemented to also foster team working. PLM benefits assessment is carried out by comparing the performances of these three stages, as described below, corresponding to different levels of collaboration. The whole systems evolution has been reconstructed and data retrieved by analysing companies' databases, documents repositories and by interviewing their staff:

Stage 1: no advanced communication and management technologies were used. Communication took place by telephone conversations (for 80% of cases), face-to-face meetings (one meeting every 40 days on average) or in writing by e-mail. Documents and data were exchanged by e-mail (95% of cases) or ftp servers (40% of cases). Sometimes also fax, traditional mail and physically exchange of CD and DVD are used (30%). Main criticalities referred to misunderstanding in phone conversations, high number of phone calls to solve a specific design problem, difficulty to organize face-to-face meetings, huge delays in performing tasks due to unread mail (both electronic and traditional), difficulties in finding past documentation, no control of the design activities nor project advances.

Stage 2: the leader company adopted a commercial PDM system properly customized to meet specific process requirements. The industrial partners accessed documents as external users with limited rights and data were always managed by actors belonging to the leader company: they uploaded data and files to specific areas of the PDM system to enable collaboration and removed data to end collaboration. Such a system allows document management and data versioning and revision and implements some "technical" workflows within the technical areas of the leader companies. However, in order to assure the security of treated data, employees of the leader company always need to filter communication with external partners (who never see the PDM system in the whole). This practice involves people on routine tasks and disturbs their everyday work. Furthermore, data sharing implies long time of uploading and downloading phase to/from the PDM areas (also few hours). When the need of collaboration has become more pressing, the PDM tool revealed all its limitations. It proved to be too rigid and close to the single company scenario.

Stage 3: Evolution of the existing PDM tools toward a PLM approach. New system functionalities have been defined in cooperation with the industrial partners. Numerous workshops have been organized to understand the main criticalities of actual processes, to choose how to evolve the adopted system to meet the extended enterprises needs and to define the technical specifications of the new PLM platform. The implemented system can be considered a good trade-off between some commercial CPDm tools and the most advanced CSCW applications. It consists of three modules able to jointly answer the requirements of the Leader Company and the design and supply chain partners (Fig.3). :

1) a PLM platform, consisting of a commercial PLM system and some ad-hoc custom applications for technical and commercial data management. It integrates some existing ICT tools (e.g. ERP system for real-time synchronization, official website for automatic data publication and upload, Hi-Plan for synchronization with project scheduling, etc.). The system allows some specific processes to be handled such as coding of special items, handling custom part registries and list pages. It is also provides some software toolkits such as an advanced viewer of 3D CAD models, a model optimizer software for de-featuring and draft automation, a Data Archive Manager (DAM) for the price list management, and a Back-Office Manager to organize the website pages.

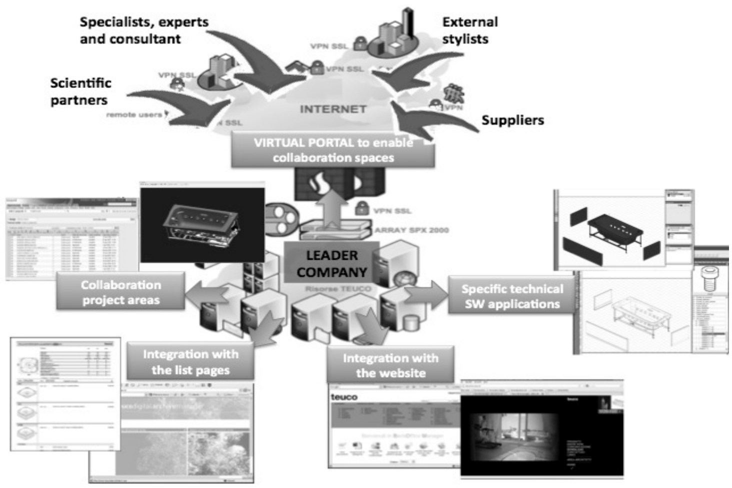


Figure 3 Conceptual representation of the implemented co-PLM system

2) a web portal to support collaboration at a technical level. It allows all partners to access technical documentations, to co-design solutions on the retrieved CAD model in the system repository at the specific project area and to share the outcomes with

the leader company. The supporting infrastructure connects intranet applications with Internet by a secure access strategy. The created Virtual Portals represent a sort of virtual places for collaboration at different levels. The virtual portals allow users directly connecting to the collaboration area of the PLM system, using different PLM system functionalities, at least those that are enabled and participating in system workflows.

3) a CRM-based product configuration tool to handle customized processes from preliminary offers to quotations and orders. It consists of a web-based toolkit for managing customer relations and custom projects (e.g. the configuration of a custom product on the basis of customer specifications, the negotiation with suppliers, designers and general contractors, the management of orders, the monitoring of project status, etc.). A set of ad-hoc applications and custom user interfaces allow integrating traditional CRM functions, ICT tools and PLM applications.

4.3 PLM evaluation in practice

The evaluation follows the method steps as described above (see section 3):

- The assessment goal is to demonstrate the benefits of adopting a co-PLM. Benefits are easily understood in terms of shortening of time to market and reduction of product development cost.
- Processes that involved the 12 SMEs and the leader company in three years of research work have been monitored. Overall 30 different projects of collaboration have been monitored, involving a total number of 99 users. Each group was made of about 8-10 persons. In particular, the analysis has been carried out on medium-sized projects of average duration (about 10-16 months) and on different design stages, from conceptual design to production release. As a consequence, different competencies were involved belonging both to the leader company to and the design and supply-chain. A sample working team was composed as follows: 1 people from the marketing staff, 1 technical director, 1-2 R&D engineers, 1 quality manager, 1-2 stylists, 1 moulding expert, 1-2 technicians from the supply-chain.
- A set of representative processes regarding the most strategic technical and business activities and involving numerous chain partners has been selected. For each of them, the evaluation metrics are chosen in order to measure satisfaction in use, process efficiency and quality of system use (Tab.1).
- Data collection is carried out according to the relative method step indications: interviews and post-hoc questionnaires to collect subjective impressions, VIA to record user behaviour, Diary Study to register all data relative to face-to-face meetings and finally reports from specific logging SW to analyse the way to use the supporting technologies. In case of the stage n.1 of system evolution data have been mainly retrieved by the study of the companies' databases, documents repositories and by interviewing the staff just employed in the companies at time.

Once data have been collected and properly elaborated, they can be compared to well-known financial indicators (e.g. the Return of Investment (ROI), Pay-Back Period (PBP)) to estimate the profitability of PLM investments.

4.4 Assessment of the achieved benefits

The method implementation in each applicative condition has lead to the collection of a great amount of data. Metrics are measured by averaging: the numbers of users' access to the PDM/PLM functionalities, its duration, the number of shared documents and data typologies (e.g. drawings, CAD files, .pdf, etc.) to assess the quality of system usage (Fig.4); the time saving achieved for each key process (Fig.5); the users' judgments to qualify the satisfaction in use (Fig.6).

The usage analysis highlights that almost the 68% of the monitored users exploits the co-PLM platform and the average duration of each access is 28 minutes. The daily number of accesses is over 280. It has been emerged that the technical departments are mostly active, even if quality departments and industrial engineering intensely use it.

Table 1 Evaluation key processes and metrics

<table>
<tr><th></th><th>KEY PROCESSES</th><th>METRICS</th></tr>
<tr><td rowspan="20">TECHNICAL</td><td>1. Product data search and visualization</td><td rowspan="26">Usage indicators: accesses [no.], document and pages [no., type], duration [min.]

Completion times: actual time of execution [h, min.] and lead time [h, days]

Satisfaction judgements (5-point scale)</td></tr>
<tr><td>2. 3D CAD models search</td></tr>
<tr><td>3. Product structures (BOM – EBOM – MBOM) visualization and navigation</td></tr>
<tr><td>4. Product-related process identification and reference</td></tr>
<tr><td>5. ERP product data search and inspection</td></tr>
<tr><td>6. New product creation (working space)</td></tr>
<tr><td>7. Work list visualization</td></tr>
<tr><td>8. New project creation (working space)</td></tr>
<tr><td>9. Data sharing managing for a new project</td></tr>
<tr><td>10. Manufacturing coding</td></tr>
<tr><td>11. ERP attributes designation</td></tr>
<tr><td>12. Engineering change creation (report)</td></tr>
<tr><td>13. Engineering change process management</td></tr>
<tr><td>14. Information recovery about engineering changes</td></tr>
<tr><td>15. Recovery of engineering changes related to a specific product</td></tr>
<tr><td>16. Approved drawings visualization</td></tr>
<tr><td>17. PDF creation of approved drawings</td></tr>
<tr><td>18. Technical drawings distribution</td></tr>
<tr><td>19. Technical data promoting</td></tr>
<tr><td>20. Material and finishing data search and inspection</td></tr>
<tr><td rowspan="6">BUSINESS</td><td>1. Creation of product supporting documentation (manuals, catalogues, etc.)</td></tr>
<tr><td>2. Supply data sharing management</td></tr>
<tr><td>3. Design data sharing management</td></tr>
<tr><td>4. Web-site product data refinement and upload</td></tr>
<tr><td>5. Web-site product data control and update</td></tr>
<tr><td>6. Return authorization management</td></tr>
</table>

Analysing the actual execution times and lead times allows the evaluation of timesaving. The first has been translated in cost saving by multiplying the saved execution time for an average hourly cost. The average hourly cost for the manufacturing chain under assessment is about 30 €/hour. Benefits on lead-time are equally important as they allow reducing time to market but they could not be seen as a direct business cost saving. The satisfaction in use has been estimated on the basis of average subjective judgements, expressed for each key process. Results reveal good system usability perceived by final users with a global judgement of 4,28 (5 is the maximum value). The previous PDM obtained a global average value of 3,8.

4.5 Best practices in PLM implementation

The experimental results highlight an intense use of PDM and PLM systems both by internal staff of the leader company and by all partners belonging to its chain. The frequency of use increases in case of co-PLM. Users engagement is improved as the system functionalities stimulate a wide participation. System accesses are frequent and their duration expresses a good performance (28 minutes). Concerning the product development process support, technical processes are quite well supported by the first PDM system, which initially implied a great time and cost saving almost in all processes (detailed numbers at authors). This result strengthens the theories about the PDM-PLM benefits and adds a concrete view of correlated cost saving. However, it is necessary to take into consideration two aspects. First, the co-PLM has been introduced into a scenario already supported by PDM tools. So, these benefits decrease in case of a low-level of computerization for data and process management. Secondly, the leader company strongly focused on the concrete adoption of the following practices:

- a clear view on the project objective;
- a right analysis of district key processes, on the basis of their crucial role and the actors involved;
- a clear implementation strategy that adheres to all companies strategies;
- a wide participation and an strong motivation;
- a close collaboration between technical and commercial roles;
- a structured evaluation method to asses real benefits that are shared with the chain.

PLM usage	No./year
USERS' USAGE	
Users	99
Users average no./month	68
Accesses	90645
Accesses avarage no./day	284
Average duration/access	28 min
DATA TYPOLOGY	
Technical drawings	22869
Text files (.doc, .odt, .pdf)	836
Data files (	658
Worklist pages	12676
Search pages	71172
ERP pages	39001

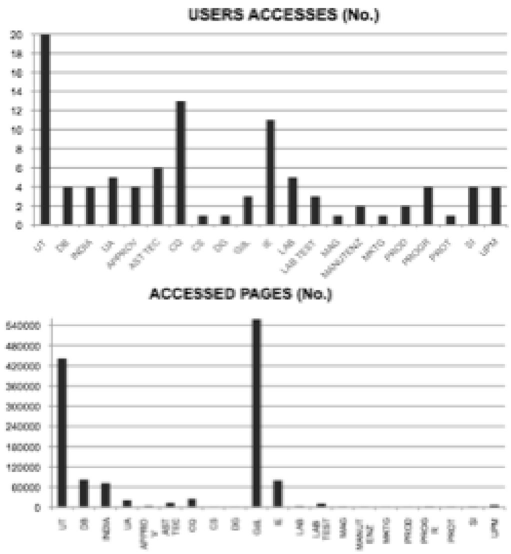


Figure 4 Results about usage of co-PLM tools in respect of different companies' departments

Experimental results in term of time saving highlight also which processes are little supported and required to be improved, such as Product data search and visualization (n.1), Engineering change creation (n.12) and Technical data promoting (n.19). About the satisfaction in use, positive response is mainly due to the graphic user interface easiness-to-use, the possibility to visualize technical drawings in real time, to the intuitiveness of accessing the work list, the project documentations in the same environment, the reduced time for data upload and download. Such a method can be easily adopted also for assessing more complex industrial networks, where more than one Leader Company is involved, just by defining a set of key processes (and relative indicators) for each supply-chain and then summing their effects to have a global evaluation. Indeed, such a situation can happen for several skilled SMEs operating often in more than one supply-chain.

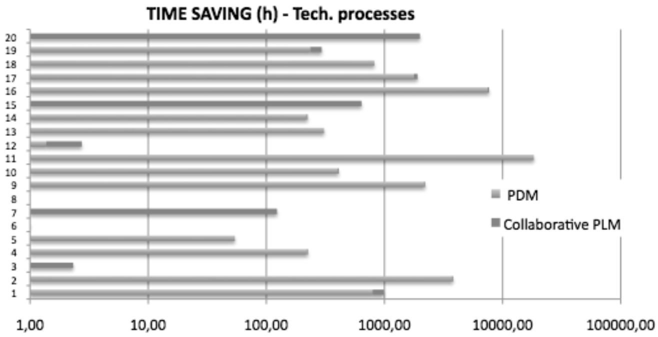


Figure 5 Benefits in terms of time saving comparing PDM and co-PLM systems (hours)

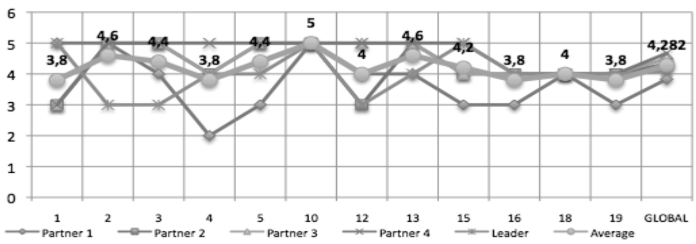


Figure 6 Users satisfaction in use (5-point scale)

5 Conclusions

This paper presents a study on the benefits of PLM systems adoption in networks of SMEs by describing an industrial experience about the implementation in a real networked context. The research tackles a very relevant problem and aims at accomplishing a crucial task in PLM: the evaluation of the achieved benefits and the comparison between potentialities and effective application. In order to do this, we defined a method to validly assess PLM advantages according to well-known industrial target and used quantitative data (time and cost) to demonstrate the tangible positive impact of PLM applications. The proposed method proves to be valid enough to be applied in case of different inter-companies business networks and key processes. Experimental results show that the creation of a robust and customized co-PLM architecture can validly improve industrial processes and becomes a valid strategy in addressing CPD. It supports product-related knowledge management, foster product innovation and adapt to the mutability of products and company structures. Further work will be addressed to extend the horizon of the present study to more complex industrial networks involving multiple Leader Companies.

Acknowledgements

Authors wish to thank Teuco-Guzzini S.p.a. (www.teuco.it) for its precious collaboration.

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Collaborative Recommendation Systems for PLM: Approach and Technological Framework

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Abstract: Currently, the manufacturing moves from resource-intensive to knowledge-intensive operations when a level of collaboration (multi-enterprise collaboration, engineering / manufacturing loop, product-service system management, etc.) of different group of PLM users increases dramatically. One of the possible ways to assist to a group of users is collaborative recommendation systems. These systems have to recommend some solutions (related to products, technologies, tools, material and business models) based on user group requirements, preferences and willingness to compromise and to be pro-active. The paper proposes an approach to developing a group recommendation system for collaborative product development based on such technologies as user and group profiling, context management, decision mining. The system allows accumulation of knowledge about user actions and decisions and uses self-organization mechanisms to compromise between group and individual preferences. Proposed approach enables formulation of recommendations for users of the same group anticipating their possible further actions and decisions.

Keyword : Collaborative recommendation system, group profiling, context management, decision mining.

1 Introduction

Increasing customer expectations and product variety cause an exploding complexity in all PLM processes, which becomes more and more knowledge-intensive. This in turn increases the level of collaboration (multi-enterprise collaboration, engineering / manufacturing loop, product-service system management, etc.) of different group of PLM users.

An intensive collaboration requires strong IT-based support of decision making so that the preferences from multiple simultaneous users could be taken into account satisfying both the individual and the group [1]. Group recommendation systems are aimed to solve this problem.

Recommendation / recommending /recommender systems are widely used in the Internet for suggesting products, activities, etc. for a single user considering his/her interests and tastes [2], in various business applications [e.g., 3, 4] as well as in product development [e.g., 5, 6]. Group recommendation is complicated by the necessity to take into account not only personal interests but to compromise between the group interests and interests of the individuals of this group. In literature [e.g., 7, 8] the architecture of the group recommending system is proposed based on three components: (i) profile feature extraction from individual profiles, (ii) classification engine for user clustering based on their preferences [e.g., 9], and (iii) final recommendation based on the generated groups. Development of clustering algorithms capable to continuously improve group structure based on incoming information enables for self-organization of groups [10].

This paper presents an approach to development group recommendation systems for PLM based on such technologies as group profiling, context management and decision mining. The usage of the approach is illustrated on the example of a company producing manufacturing equipment that has more than 300.000 customers in 176 countries supported by more than 50 companies worldwide with more than 250 branch offices and authorised agencies in further 36 countries. Section 2 represents the overall context-driven system architecture. Section 3 describes knowledge representation formalism. Then, the user clustering algorithm is presented followed by the explanation of identification of common preferences. Major results are summarized in the conclusion.

2 Group Recommendation System Architecture

The developed group recommendation system architecture is presented in Figure 1. It is centralized around the user clustering algorithm [11] originating from the decision mining area [12-14]. However, the development of the algorithm has made it possible to use it for building self-organizing user groups. The proposed clustering algorithm is based on the information from user profiles. The user profiles contain information about users including their preferences, interests and activity history. A detailed description of the profile can be found in [15]. Besides, in order for the clustering algorithm to be more precise, this information is supplied in the context of the current situation (including current user task, product(s) she/he works with, time pressure and other parameters. The semantic interoperability between the profile and the context is supported by the common ontology.

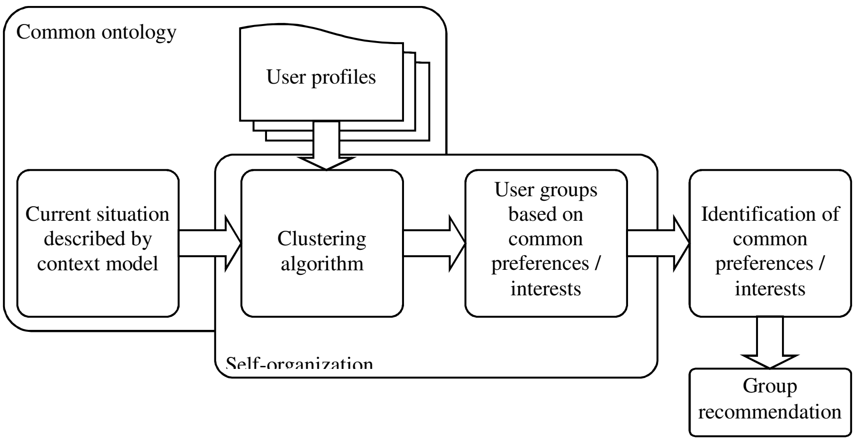

Figure 1. Group recommendation system architecture

The user profiles are considered to be dynamic and, hence, the updated information is supplied to the algorithm from time to time. As a result the algorithm can run as updated information is received and update user groups. Hence it can be said that the groups self-organize in accordance with the changes in the user profiles and context information.

Since, in the company considered as an example, the major difference between users is the group of products they work with, the generated groups are expected to be product related. However, in other environments this is not necessary to be the case and groups can be process-oriented, resource-oriented or other.

When groups are generated the common preferences/interests of the groups can be identified based on the results of the clustering algorithm. These preferences can be then generalized and analyzed in order to produce group recommendations.

3 Knowledge Representation Formalism

Since the user profiles and the current situation context are analyzed jointly, it is reasonable to use the same formalism and terminology for their representation. This is achieved via usage of the ontology. In the proposed approach the formalism of Object-Oriented Constraint Networks (OOCN) is used (its detailed description can be found in [16]) for knowledge representation in the ontology. Application of this formalism makes it possible to perform automatic definition of configurable complex products based on the required functions and other constraints specified by the customers or engineers. It provides primitives for modelling classes, class hierarchies and other class structures, class attributes, attribute inheritance, attribute ranges, and functional dependencies. According to this formalism the knowledge is represented by sets of classes, class attributes, attribute domains, and constraints. The set of constrains consists of constraints describing “class, attribute, domain” relation; constraints representing structural relations as hierarchical relationships “part -of” and “is-a”, classes compatibility, associative relationships, class cardinality restrictions; and constraints describing functional dependencies. According to the formalism ontology A is defined as:

$A = \langle O, Q, D, C \rangle$, where

O – a set of *object classes* (“classes”)

Q – a set of class *attributes* (“attributes”);

D – a set of attribute *domains* (“domains”);

C – a set of *constraints* used to model relationships.

The set of constraints includes six types of constraints for modelling relationships occurring in formats / languages for ontology representation and compatible with constraints supported by constraint solvers:

C_1 – (class, attribute, domain) relation used to model triple of classes, attributes pertinent to them, and restrictions on the attribute value ranges;

C_2 – taxonomical (“is-a”) and hierarchical (“part-of”) relations used to model class taxonomy and class hierarchy respectively;

C_3 – classes compatibility used to model condition if two or more instances can be parts of the same class;

C_4 – associative relationships used to model any relations and axioms of external ontologies neglected by the internal formalism;

C_5 – class cardinality restriction used to define how many subclasses the class can have;

C_6 – functional relations used to model functions and equations.

Such representation of knowledge can be interpreted as a constraint satisfaction task and used by a constraint satisfaction/propagation engines for reasoning and constraint for optimization tasks.

Below, some example constraints are given:

an attribute *costs* (q_1) belongs to a class *cost centre* (o_1): $c^I{}_1 = (o_1, q_1)$;

the attribute *costs* (q_1) belonging to the class *cost centre* (o_1) may take positive values: $c^{II}{}_1 = (o_1, q_1, R^+)$;

a class *drilling* (o_2) is compatible with a class *drilling machine* (o_3): $c^{III}{}_1 = (\{o_2, o_3\}, True)$;

an instance of the class *cost centre* (o_3) can be a part of an instance of a class *facility* (o_4): $c^{IV}{}_1 = <o_1, o_4, 1>$;

the *drilling machine* (o_3) is a *resource* (o_5): $c^{IV}{}_1 = <o_3, o_5, 0>$;

an instance of the class *drilling* (o_2) can be connected to an instance of the class *drilling machine* (o_3): $c^V{}_1 = (o_2, o_3)$;

the value of the attribute *cost* (q_1) of an instance of the class *facility* (o_4) depends on the values of the attribute *cost* (q_1) of instances of the class *cost centre* (o_1) connected to that instance of the class *facility* and on the number of such instances: $c^{VI}{}_1 = f(\{o_1\}, \{(o_4, q_1), (o_1, q_1)\})$.

4 User Clustering Algorithm

Due to the specific of the tasks in the considered company (product orientation) the implemented algorithm [adapted from 11] of user clustering is based on analysing user generated solutions and has the following steps:

1. Extract words/phrases from the solution (text processing).
2. Calculate similarity between the solution and ontology elements (i.e. compare text strings extracted from the solution and names of classes and attributes). The algorithm of fuzzy string comparison similar to well-known Jaccard index [17] is used for this purpose. It calculates occurrence of substrings of one string in the other string. For example, string "motor" has 5 different substrings (m, o, t, r, mo) contained in the string "mortar". The total number of different substrings in "motor" is 13 (m, o, t, r; mo, ot, to, or; mot, oto, tor; moto, otor). The resulting similarity of the string "motor" to the string "mortar" is 5/13 or 38%.
3. Construct weighted graph consisting of ontology classes and attributes, and users. Weights of arcs are calculated on the basis of (i) similarity metrics (i.e. they are different for different user solutions) and (ii) taxonomic relations in the ontology.
4. Construct weighted graph consisting of users (when classes and attributes are removed arcs weights are recalculated).
5. Cluster users graph.

For the clustering procedure a weighted user – ontology graph is considered. It contains three types of nodes: C – classes from the ontology, A – attributes of the classes, U – users.

The graph consists of two types of arcs. The first type of arcs I (CA, CC) is defined by the taxonomy of classes and attributes in the ontology. The second type of arcs II (CU, AU) is defined by relations between user solutions and classes/attributes (cf. Figure 2a).

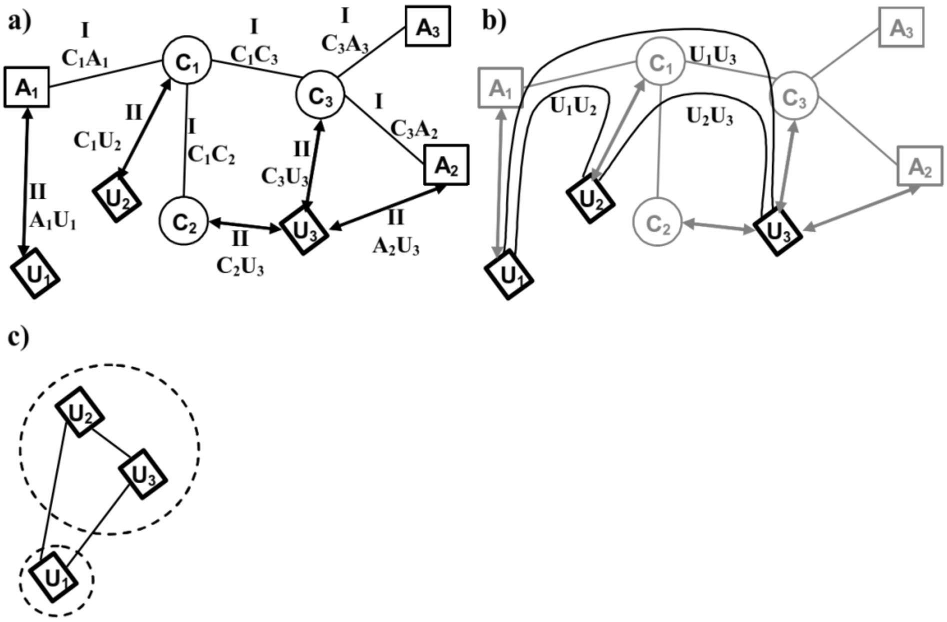

Figure 2. Weighted user – ontology graph and user clustering procedure

Weights of arc between nodes corresponding to classes and users CU_{weight} and corresponding to attributes and users AU_{weight} are defined via the similarity CU_{sim} and AU_{sim} of the class or attribute (calculated via the fuzzy string comparison algorithm described above). The similarity is a property of relations between class – user/solution or attribute – user/solution. Weights of arcs are defined as follows: $CU_{weignt} = 1 - CU_{sim}$; $AU_{weight} = 1 - AU_{sim}$.

Arcs CA and CC tying together classes and attributes via taxonomic relations (defined by ontology relations class-class, class-atribute) have CA_{weight}, $CC_{weight} \in (\varepsilon, 1)$ defined empirically. CC_{weight} means arcs' weight of linked classes in the ontology. CA_{weight} – arcs' weight of linked attributes and classes.

Since users are represented by their solutions, based on this graph the solutions and weight consequently users are clustered on the basis of the lowest weights of connecting arcs.This is performed in the following sequence. First, the shortest routes between users are calculated (cf. Figure 2b). E.g., weight of the arc U_1U_2 will be calculated as follows: $U_1U_{2\ weight} = A_1U_{1\ weight} + C_1A_{1\ weight} + C_1U_{2\ weight}$; weight of the arc U_2U_3 can be calculated in 3 ways, it is considered in Figure 2b that $U_2U_{3\ weight} = C_1U_{2\ weight} + C_1C_{3\ weight} + C_3U_{3\ weight}$ is the shortest one; etc. Based on the calculated weights a new graph consisting of the users only is built (cf. Figure 2c). The value of the parameter D_{max} is set empirically. Assuming that $U_1U_{2\ weight} > D_{max}$, $U_1U_{3\ weight} > D_{max}$, and $U_2U_{3\ weight} < D_{max}$, two clusters can be identified: the first cluster includes users U_2 and U_3, and the second one includes customer U_1 (dashed circles in Figure 2c).

The algorithm can run as updated information is received and update user groups thus providing for self-organizations of user groups in accordance with the changes in the user profiles and context information.

5 Identification of Common Preferences/Interests and Group Recommendations

User preferences consist of attributes (properties) and/or their values, classes (problem types), relationships (problem structure) and/or optimization criteria that are usually preferred or avoided by the user. The preference revealing can be interpreted as identification of *patterns of the solution selection* (decision) by a user from a generated set of solutions by the system. The ability to automatically identify patterns of the solution selection allows to sort the set of solutions, so that the most relevant (to user needs) solutions would be in the top of the list of solutions presented to the user.

Currently, three major tasks of identification of user preferences can be selected:

1. Identification of *user preferences based on solutions generated for the same context*. In this case the problem structure is always the same, however its parameters may differ.
2. Identification of user *preferences based on solutions generated for different contexts*. This task will be more complex then the first one since structures of the problem will be different.
3. Identification of *user preferences in terms of optimization parameters*. This task will try to identify if a user tends to select solutions with minimal or maximal values of certain parameters (e.g., time minimization) or their aggregation.

Based on the clusters identified via the clustering algorithm described above the user preferences can be identified as common features of the solutions grouped into the clusters.

Here presented example illustrates clustering of 10 solutions and 26 classes related to them (attributes are omitted). The common ontology was built semi-automatically based on existing electronic documents and defined rules of the model building in the company. The resulting ontology consists of more than 1000 classes organized into a 4 level taxonomy, which is based on the VDMA (Verband Deutscher Maschinen- und Anlagenbau - German Engineering Federation) classification. Figure 3 demonstrates the solutions (some of the solutions are replaced with meaningful patterns), classes and relevance between them: the darker cells represent classes corresponding to the appropriate solutions with a higher degree of relevance. After the clustering procedure the results represented in Figure 3b have been obtained. The dotted horizontal lines separate solution groups from each other. Presented example is rather small and is used for illustrative purposes only, however having enough statistics it is possible to identify real regularities in users interests.

6 Conclusion

The paper presents an approach to development of group recommendation system for PLM. The approach is based on application of such technologies as user and group profiling, context management, decision mining. It enables for self-organization of user groups in accordance with changing user profiles and the current situation context.

Acknowledgment

Some parts of the research were carried out under projects funded by grants # 09-07-00436-a and # 11-07-00045-a of the Russian Foundation for Basic Research, and project # 213 of the research program “Intelligent information technologies, mathematical modelling, system analysis and automation” of the Russian Academy of Sciences.

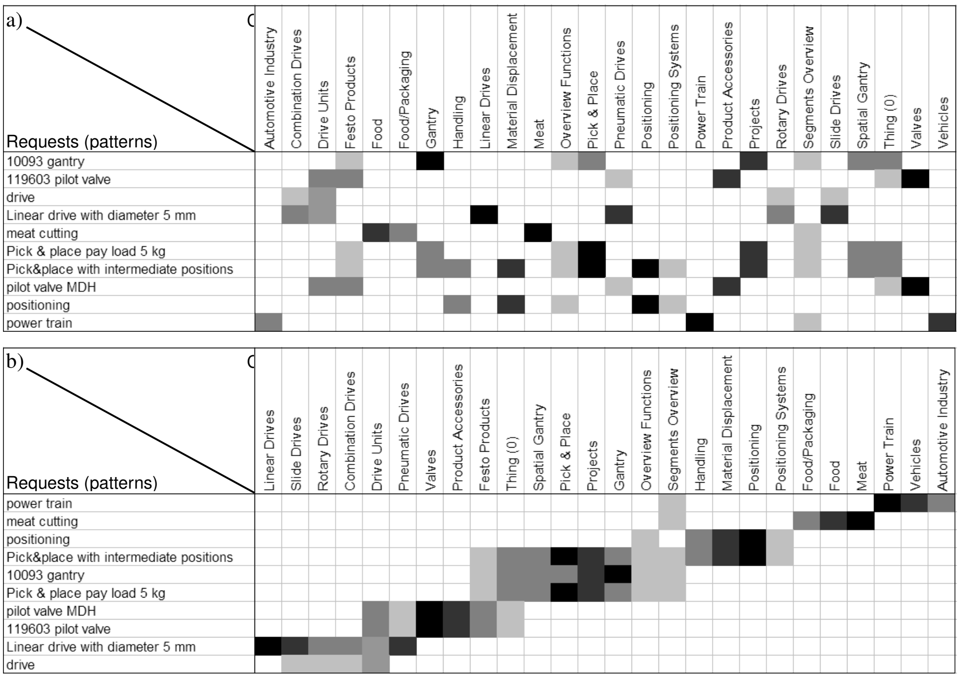

Figure 3. Example results of the clustering procedure. Darker cells mean higher similarity between requests/patterns (rows) and ontology classes (columns). Figure (a) represents requests and classes before clustering, figure (b) – after.

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Chapter 5
Data Management and Traceability

PDM suitability study for CAE data management

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Abstract: In the last decade, the major CAE software vendor understood how the increasing use of simulation needs systematic methods to manage the data generated in the process. Without reinventing the wheel these companies reused the concept and architecture typical of Product Data Management system (PDM) and tailor made the data model to support CAE application. Moreover, many companies desire to leverage their existing PDM systems as the primary repositories of CAE data. We first analyze the adequacy between the classical capabilities offered by the commercial PDM systems compared to the needs of simulation data and process management, expressed in the literature and by our industrial partners. Then, we defined a suitable data model (structure and associated metadata) in order to organize and store CAE data in traditional PDM. Finally we formalized the PDM business logic that will support that data model and the internal working procedure of the company. These models are the inputs for a pilot implementation done with a commercial PDM, PTC Windchill. At the moment the use of PDM is not part of the CAE analyst mindset. For this reason we develop a simple client that could help the analyst to organize his/her data according to the predefined data model, forcing him/her to provide the necessary metadata that describe the task that he/she is performing and finally translate all these information into a Windchill compliant XML, that can be easily uploaded to the PDM.

Keyword: CAE data management, PDM, SDM, Simulation processes

1 Introduction

In order to reduce the time-to-market and to improve the quality of the Product Development Process (PDP), companies currently use more and more digital simulations to qualify the product as soon as possible. Computer Aided Engineering (CAE) applications offer the ability to solve complex engineering problems, allowing companies a reduction of traditional test based approaches in order to evaluate product performance. Though CAE will not replace physical tests, it lets companies evaluate a multitude of product use cases that would be expensive to test otherwise [1]. At the same time, the increasing computational power allows running simultaneous analysis with multiple parameters by methods such as stochastic simulations, optimization and multi-scenario analysis. The introduction of these new methods results in a dramatic increase of the number of simulations [2]. Thus, in CAE the Moore's law describing the roughly exponential growth of the computational power does not really help because simulation complexity is growing approximately with the same rate. Together with complexity comes the amount of data generated. In this field industries are leading the research because of they are facing these problems every day. Pioneers in this field are the BMW group and later other German automotive companies like Audi. Almost ten years ago they realized how they cannot rely on computer technology advances to solve this performance issue [2]. It is interesting to notice that even after a decade of experience they both claim how stochastic analysis data is not stored entirely in their simulation data management (SDM) systems, only key results are extracted for long lasting storage. This gives an idea on how challenging management of CAE data can be.

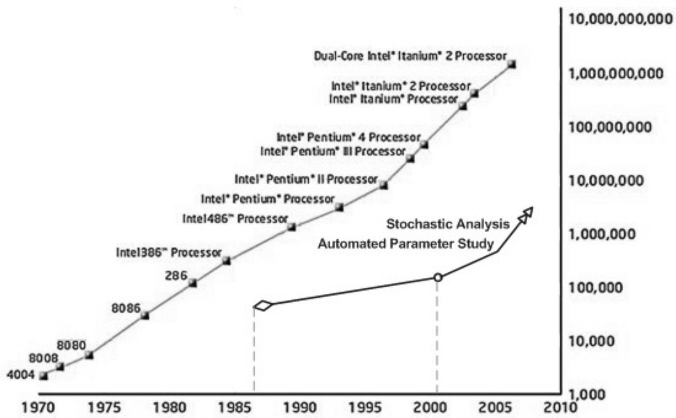

Figure 1: Simulation Data growth and relation with the number of transistor in a chip.

In order to efficiently use CAE to drive the design and deliver full business benefits, the simple storage of the simulation data is not enough. Moreover, the capitalization of the knowledge created during all simulation tasks is as important as the results of these tasks, since the efforts to produce a good simulation result are still important. The concept of Simulation Lifecycle Management (SLM) approach has been proposed to tackle the problem [3]. Furthermore, it is necessary to identify and store the higher engineering process that the simulation is part of. Very few scientific works are focusing on this capitalization [4].

Currently, most of the data is still managed by moving flat files and organizing them in directory structures according to personal taste. To tackle this problem all the major CAE software providers have developed their own data management system that is essentially a lightweight version of PDM tuned to support CAE data and processes. Moreover, it is quite unusual to have a standalone SDM system. In most of the cases it is connected with a PDM for retrieving the geometry on which the analysis is carried out. This solution introduces an additional level of complexity and cost. For these reasons, many companies desire to leverage their existing PDM systems as the primary repositories of CAE data. Nevertheless, Jenkins [5] found out that lack of commercially available PDM for CAE data is the largest unmet need relating to implementing digital simulations and analysis. The only effort in this direction is done by Siemens and their PLM solution Teamcenter.

In this article we first analyze the capabilities offered by the commercial PDM systems to fulfill the needs of simulation data and process management. Then we present a suitable data model (structure and associated metadata) together with the business logic that captures the typical workflows and roles of a simulation unit in a company. These models can be used as an input for the configuration of any PDM system, while for our pilot implementation we choose PTC Windchill because is currently used by one of our industrial partner. Finally, we discuss the challenges embedded in the management of CAE data that partially explain the lack of solution in PDM domain.

2 Current capabilities of commercial PDM systems

PDM systems are traditionally used for CAD data management, product configuration and change control [1]. These systems are not generally tuned for managing CAE data [6]. However, PDM systems have a set of common core functionalities that make them suitable to manage also different kind of documents. In this chapter we present these functionalities pointing out their role in the management of CAE data and processes.

DATA STORAGE: Any data management system must implement a strategy to store safely and efficiently the data. Here with efficiently we refer to the capability of rapidly accessing the data. In modern PDM this capability is implemented trough indexing server. One of our industrial partners has pointed out how their system lack of this performance. This is a serious concern when trying to manage huge number of different files with large dimensions, typically produced by CAE simulations.

CONTROLLED ACCESS: “Who” access “what”, and which operation (“how”) can do on the specific object. A scenario of a Simulation group must be thought in order to identify the roles (For example Analyst, Chief Analyst, etc).

DATA LOCK: When an object has been checked out, others may view the checked out copy, but they cannot modify it. This prevents others from making changes to the object before you have completed your work.

DATA VERSIONING: Is the way how keep track of changes on specific object (file) stored in the system (For example: all the time that an object is checked-in, the metadata representing its version A.1 A.2….B.1, is updated).

METADATA DEFINITION: To enable queries to the system not only based on the name of the object we need to define an essential set of metadata associated with the object that we want to store.

CLASS EXTENSION: Out-of-the-box PDM data type (like Parts, CAD document, Documents etc.) can be augmented by adding additional metadata. The extended type inherits the methods (actions that can be performed with the object) of the original type, while custom policies and configurations of rules can be specified for it.

DATA LIFECYCLE: For each data type is possible to define the maturation stages associated with process that generates the object (For example: working, released, submitted, approved, and archived). In the next chapter we propose a possible schema for CAE data.

DATA WORKFLOW: After defining the roles of working team and the lifecycle of the data, we need to capture the dynamics of the group for each stage of maturation of the data (its lifecycle). In the next chapter we present some of the possible work dynamics that might occur in a simulation unit of a company. Data lifecycle and workflows might vary according to current practice of a company.

3 Challenges involved in CAE data management

According to [2], using expanded PDM systems to manage simulation data is a misleading approach. In their view the focus and the structure of a PDM system are essentially different from the ones that CAE management system should have. They correctly point out how one simulation does not carry very much information, but always has to be put in context to other simulations. A simulation project consists of multiple simulations in which the model itself and the load case are varied. By comparison of these variations, trends and insights can be derived which represents the key results communicated back into the design process. As a result, the data management system for simulation data is more oriented around structuring all the different variants.

While we agree on the last point, we disagree when they claim that there is no equivalent variant structure in a PDM system. PDM systems are not monolithic pieces of software. They are developed keeping in mind that high level of configuration and personalization are possible and necessary to meet specific business needs. This flexibility can be exploited in order to manage document with different nature then CAD, as suggested by [1]. The configuration of users rights, data lifecycle and data workflow are typical tasks of any PDM business administrator. The real challenge is how to handle data with essentially different structure then CAD. In PDM the data is organized and visualized in a way that reflects the assembly tree structure, because it is a natural way for a CAD designer to explore the available data searching for parts and sub-assembly. In CAE, the CAD is the geometric entity on which certain physical properties must be verified. In this context the structure of the assembly is useful only to remove irrelevant geometric details in order to verify the requested properties. Furthermore, there are a very large number of data files of different types, used in different contexts. Results from one analysis are often used as inputs for different analyses.

In conclusion, the data involved in CAE resemble a complex network much more than a simple product structure. In the figure 2 we give an example on how product data and simulation data might relate to each other.

Besides the data structuring, another recurrent argument is how PDM are not supporting CAE processes. Considering the history of the supporting tools for CAE activities, we find this statement quite misleading. CAE software vendor provided tools known as process builder before developing their data management solution. The tendency of these vendors is to sell the process builder and the data management system as one solution, but essentially one tool does not necessarily need the other to perform its function. The process builder helps the analyst to develop complex scripting trough a GUI, linking different software tools and analysis. Scripts usually contain a series of commands written in a certain language and stored in human readable ASCII text format. We do not really see how this kind of file cannot be stored exactly like any other document in the PDM. The real concern comes only on the data referenced in the script. To re-run the script it is fundamental to keep track where this data has been stored.

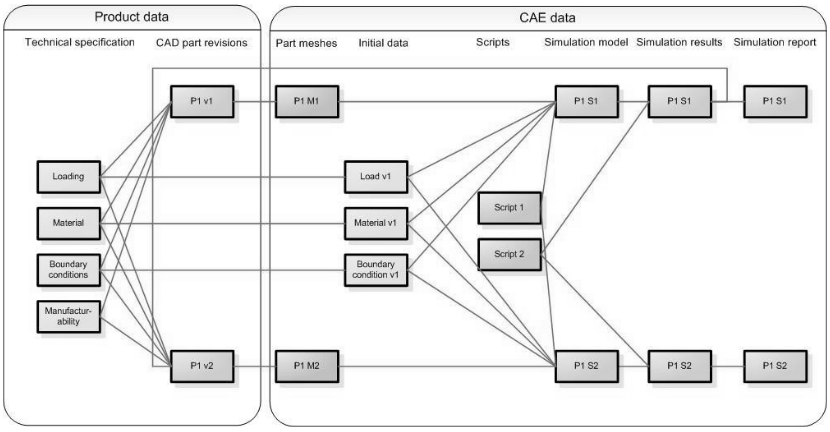

Figure 2 - Network resembling the relation of product data and CAE data.

4 Proposed data model for CAE data management

The considerations done in the previous chapter were the driver for the development of a data model for CAE data management. As mentioned above, CAE data cannot be organized according to a hierarchical physical assembly. A logical disposition consists in organizing simulation data according to the projects and tasks that were performed in order to generate that data. Joshi [1] suggests how the inspection of published standards such as STEP AP209 and PDES's EACM can provide a deeper insight into the kind of objects needed to effectively capture CAE data. These standards are primarily intended to establish data exchange formats but they also provide data modeling clues. We followed that suggestion, sharing the view that Joshi has on the structure of the data. Our contribution tries to go one step further providing the guidelines to extend that model for different CAE domain and integrating relevant concepts implemented in commercial SDM systems [7].

4.1 Method, Simulation_Task and Simulation_Process

In the development of the data model we started with the identification and formalization of the common aspects involved in the execution of a CAE simulation. Determinant insights on this model come from the logic implemented in the commercial SDM, MSC SimManager [7].

METHOD: is the sequence of actions (eventually coded into an automatic script) that allows the analyst to produce a certain output given certain input. A method is defined by experts and represents the best practices of a company. Sharing and reuse of these “best practices” guaranty the quality of results that a simulation delivers.

SIMULATION_TASK: is a single analysis performed with a certain software tool applying certain method by a certain analyst.

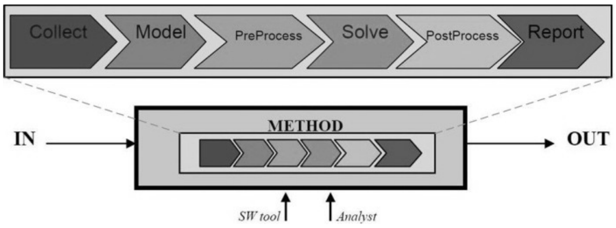

Figure 3 – Simulation_Task and steps of the applied method used to perform it.

SIMULATION_PROCESS: is a series of linked *Simulation_Task*. The results of each task are used to perform the next task in order to achieve a specific goal.

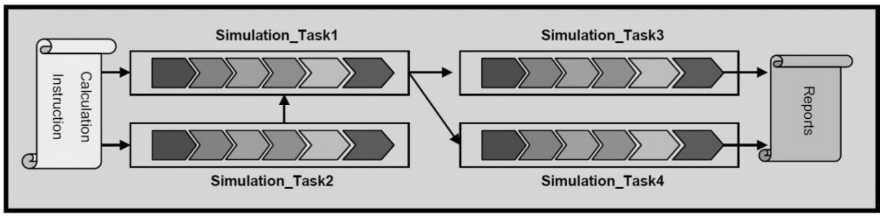

Figure 4 – Simulation_Process is a collection of linked of Simulation_Task.

4.2 Simulation_Task data structure

While performing their tasks, analysts organize the data generated in a directory structure of their preference. Our goal is to find the most generic structure that can represent a simulation task, regardless the type of simulation performed. In [1], Joshi proposes a structure to organize the data analysis generated in finite element analysis. We understand how the higher levels of that structure are common to every simulation task regardless the domain of simulation. Our idea is to maintain the same top level structure for every simulation task and customize the lower levels. We propose a schema with two levels of specialization applied to the main structure. The first level introduces elements and metadata specific to simulation domains (Finite Element Analysis , MultiBody Simulation, Computational Fluid Dynamics, etc.). The second level introduces elements and metadata specific to simulations performed with particular software. Figure 5 clarifies this specialization schema.

The main structure of a simulation task is depicted in figure 6. The main elements of this structure are:

- <u>Documentation</u>: Here are stored all the documents that describe the task and its goal. A standard template must be filled by the analyst before performing the task assigned.
- <u>Analysis</u>: Here are stored all the files and information used to perform the task and raw results of the simulation.
- <u>Results</u>: Here are stored the results of a Simulation_Task. The raw results are processed (manually or automatically) and a standard report template is created by the analyst.

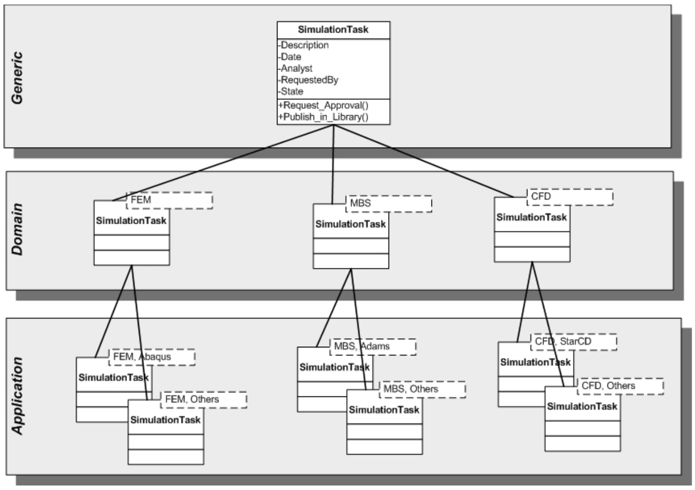

Figure 5 – Specialization of Simulation_Task according to the domain and application

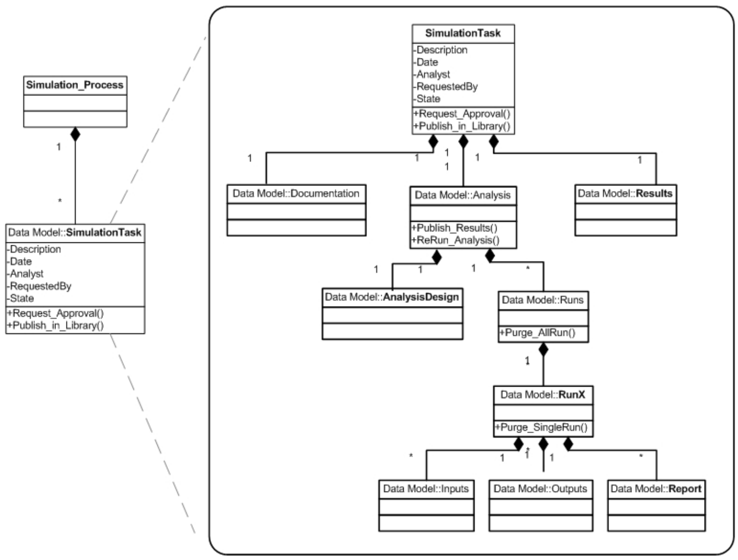

Figure 6 – Main structure common to all the Simulation_Task

The Analysis element contains two child objects, which need a clarification. Most of the time, performing an analysis is an iterative process. Each iteration, also known as Run, is a configuration of a CAE master model where inputs, parts, boundary condition, etc. are modified.

In our data structure, the CAE master model and all the data common to all the Run are stored in AnalysisDesign. The idea is that in AnalysisDesign are stored all the data necessary to re-execute all the Run. Each Run has (1) an Input object where is stored the input deck for that iteration, (2) an Output object where raw results are stored, (3) a Report object were intermediate plot and results are extracted (manually or automatically) from the raw results. A Simulation_Task will have as many Run objects as many iterations are required to conduct the analysis. The Runs object is simply a container for the Run performed.

The structure in figure 6 shows the associated attributes of each object; for example the object Simulation_Task is described by Description, Date, Analyst, RequestedBy and State. The field under the attributes contains the actions that can be performed on the object. Within the task it should be possible to delete a single iteration of analysis with +Purge_SingleRun(), delete the whole intermediate results with +Purge_AllRun() and re-execute the entire analysis restoring all the intermediate results with +ReRun_Analysis(). The action +Publish_Results() call an automatic procedure that post-process and extract the key results of each run and publish them into the Results object. The actions +Request_Approval() and +Publish_in_Library() have effects outside the Simulation_Task. They interact with the business logic of the PDM and are explained in the next paragraph.

The complete definition of each specialized structure according to the domain and the application is still under development. Besides the structure, an important aspect in the definition of a Simulation_Task is the identification of the associate attributes or metadata. On the proposed structure, we identify an initial list of them. However, a complete definition is still under development and it might vary according to the preference of the enterprise. On this subject we consider two approaches. In the first we try to define a complete set of metadata for the specific object using as reference standard like STEP. For example we can refer to STEP AP209 in order to identify the relevant metadata associated with the input deck of simulation task performed in the FEA domain. The second approach defines the set of metadata asking one simple question: which kind of query you want to perform on your data? For example if you are searching for a simulation performed by X in date Y: the name of the analyst and the date when the analysis has been performed must be added as metadata.

4.3 Implementation of the Simulation_Task in PTC Windchill

As mentioned in the previous chapter PDM systems are tuned to manage product structure. The central object is usually called a Part or an Item. Parts can contain other parts. A product structure is a hierarchical arrangement of such objects [1]. It is a common error to think that a Part is somehow synonymous of a CAD part. A Part or Item is simply a container for documents (CAD, others or both) with associated certain action that can be performed on that object. A combination of these objects can create any arbitrary complex structure.

The Simulation_Task data type has been created using the runtime typing capability of Windchill PDMLink. It allows extending out-of-the-box business objects by adding additional attributes, or by adding new object types with different attribute sets without changing the object model and writing code. The derived object inherits the behavior (actions that you can perform on the data type) of its parent type. It is possible to define custom life cycles, associated workflows, team templates, storage locations, and versioning schemes for the derivate type. In the next paragraph we will present these configurations. In our implementation we choose the class WT Part (Windchill Technology Part) as base class for the definition of the Simulation_Task object. The characteristics that make WT Part suitable as base class are: (1) the capability to create hierarchical structure through editing the bill of materials (2) the possibility of the structure items to contain any kind of documents (CAD, CAE, Microsoft Office, etc.) (3) the possibility to set states and promotions that are triggering events in the workflow presented in the next paragraph.

4.4 Roles, Data Lifecycle and Data Workflow

While the model proposed for the Simulation_Task can be applied in any enterprise, roles, data lifecycle and data workflow might vary according to the current organization and practices of a company. Here we present a possible scenario that might occur in many simulation units:

- Roles: we identify essentially two main roles, Chief analyst and Analyst. These two roles will interact with the Designers team and managers (for example, Project Manager and other kind of Managers might need to receive feedback regarding the completion and progression of the requested simulations).
- Data Lifecycle: the maturation stages of a Simulation_Task are: In Work, Under Review and Released.
- Data Workflow: the interactions between Chief analyst and Analyst and the associate maturation stages of data are presented in figure number 7.

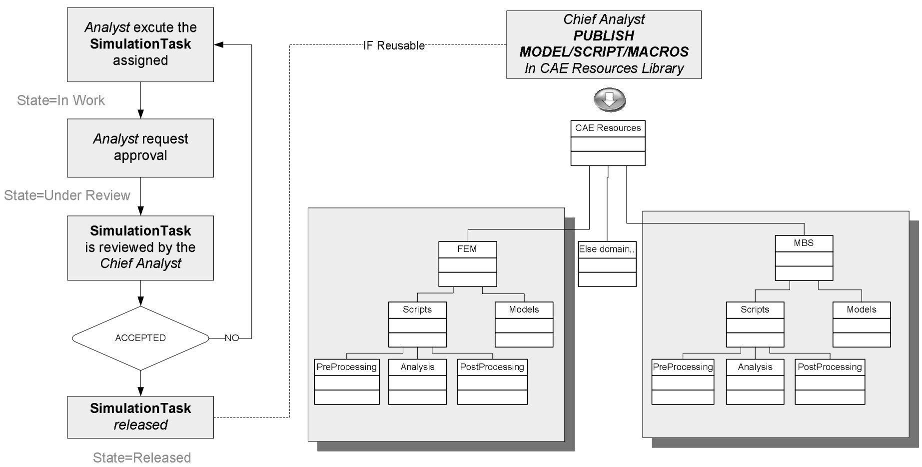

Figure 7 – Data Workflow, Data Lifecycle and structure of the CAE Resources Library.

The implementation of these configurations are typical tasks of any PDM business logic administrator and do not need any further explanations.

4.5 XML, interoperability and usability issues

The logic of Windchill PDMLink does not allow to copy and paste all the items within a Simulation_Task. Even when you create a template, only the main object without its internal item can be instantiated. It would be a cumbersome process if the analyst needs to manually recreate all the items of a Simulation_Task, upload all the requested documents and finally fill the related metadata. To simplify this process, it is possible to formalize the Simulation_Task structure with all the necessary documents and their metadata into a Windchill specific XML file format, that can be uploaded all at once into the PDM system. This approach drastically reduces the number of necessary interactions, increasing the user acceptance of the system.

Currently we are developing a client side component that would guide the analyst in organizing the data according to the proposed Simulation_Task structure, by directly extracting the metadata from documents, and finally generating the Windchill compliant XML.

5 Discussion and future work

In this article, we analyzed the suitability of PDM systems for the management of CAE data. Our conclusion is that this kind of systems has all the necessary core functionalities to also manage CAE data. Future works will focus on the evaluation of the performance and usability of PDM compared with specialized simulation data management systems. Initial tests will be conducted in our laboratories but to obtain relevant information, we need to test these systems in real industrial environment, starting from the one of our partners. We need to receive feedback from the real end user of the system. User acceptance is the key factor in the success of a data management system. For this reason having a user-friendly and responsive system is not only a wish but a compulsory requirement. Furthermore, future lines of research must deal with the selection of particular IT infrastructure and network solutions to deliver high performance systems.

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An effective release process in Building and Construction

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Abstract: The level of failure costs in Building and Construction is still at a high level. A major cause of failure costs is the use non valid or wrong documents / models in the process.
The release process is about controlling the quality of documents / models in a structured way.
The major three attributes of a document / model to manage it are its identity, its version and the (maturity) status of this version. In Building and Construction processes the status of a document / model is hardly used. The article proposes a release process in the environment of an extended enterprise based on the natural principals of releasing information. This basic release process will be extended to implement concurrent engineering, the aspect of mutual involvement, in a structural way in the release process.

Keywords : Document / model release process; document lifecycle; document version and status

1 The current situation

1.1 Introduction

Why perform research on such a simple event of approving a created document and signing it to show it is ready? And if the document has to change it will be approved again and the latest date will show which document has to be used in the project. Further good communication and management have to assure that the Building and Construction process is efficient, effective and will deliver the intended results. Of course this formulation is a caricature of the real situation. But it illustrates the main motivation for this research. It is meant to prove that a good release process is obligatory for good Building and Construction process delivering the specified results with a minimum of failure costs. In other words good communication and clever organisations are not enough.

Although the reason for the research lays in today's Building and Construction practices the research has been broader and the proposal is generally applicable.

1.2 Common practice today in Building and Construction

It is common practise that documentation defining buildings and constructions is a collection of documents ordered in folders per discipline and often located at different locations. And of course, in different systems too, but this is not considered as the major issue.

A document in this article is a unit of information of any kind related to physical objects to be realised. Thus models are included.

Because documents are changing the information is not in the document but in the document version often called revision.

A document has a lifecycle within the release process meaning the document version goes through a number of maturity statuses. This status, sometimes called state, is a projection of the maturity of the document or model and is telling the user where it is in its release process and for what activities the document is allowed to be used.

Fuzzy meanings in daily practice of essential characteristics of a document are leading to unidentified document versions and improper use of documents.

For example it is quite common that revisions are handled rather careless. For example a document revision C has to be changed. In order to avoid a high number of revisions the author of the document will change the revision when the change is fully completed and submitted for release. In the meantime he has distributed a few alternative documents to get comments and approval. The result is that there are more document versions than proper identified versions. It will be easy to use non proper information.

Another example is the fuzzy use of the status of a document. Building and Construction processes usually use a pseudo lifecycle of two statuses DRAFT and FINAL. It is called a pseudo lifecycle because in case of a change of a final document the status of the new document version is not set to DRAFT but is left FINAL. In general this means that the status of a document version in Building and Construction does not give its user any information. This easy leads to improper use of the document varying from carrying out a complete analyses where only professional comment was expected until shopping on the bases of documents that were not supposed to be released.

1.3 Leading problem

The leading problem is that in spite of many new IT tools applied within Building and Construction and experimenting with Systems Engineering (Blanchard 2008)[1] the amount of failure costs seems to increase[2].

Consider fig. 1 representing a single activity given in a diagram with input, output, control and tools. The development process is a series of these individual activities. Errors on business levels arise when individuals in the project do not deliver the needed results, e.g. documents on which buildings and constructions are based.

Basic causes for not delivering the required results are:

1. Insufficient management and communication;
2. Insufficient skills and experiences of individuals;
3. Insufficient tools, including libraries and procedures, to do the job;
4. Flaw order and or input documents (requirements).

Guess[3] and Watts[4] are discussing flaw documents or requirements as the main cause for failure in industrial product development. Veerman[5] and Vrijhoef[6] are more concerned with management and communication. Reefman did in 1994 an evaluation of the project New Headquarter Fire Department of The Hague and also concluded that wrong documents are a relevant cause for failure costs (Internal document AEGOR / HBM).

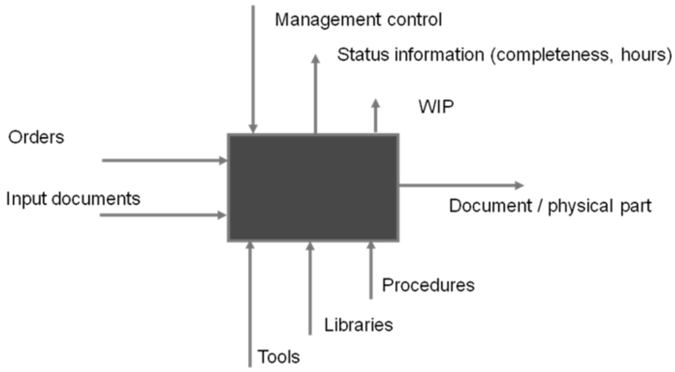

Figure 1 The process of creating a document (or part)

This research is dealing with the problem of flaw and erroneous input documents. Due to false input documents the individual designer, engineer and other project workers will encounter the following problems related to their input documents:

- Documents are missing;
- Documents are not consistent;
- Documents are not clear for its users;
- Documents are not valid.

Output cannot expect to be all right if the input is not good. This means a basic question is how to get (and keep[1]) good documents in the product development process. This research is about how to get good documents in Building and Construction projects.

The definition of a good document is given by Guess [3] as clear, concise and valid. Pels [8] has add to this: " - and consistent with related documents." Special attention needs to be given to the word valid. Valid means that two conditions have to be fulfilled:

1. Following the document by the letter will result in the intended result [3];
2. The document has been authorised to be used in the project, meaning the project or programme management is accountable for all consequences of using the document.

The research approach is looking to industry e.g. recognized authorities Guess and Watts and a literature study on what is going on to improve the Building and Construction process especially regarding document release.

To obtain good documents it is assumed that there is a need for a high quality release process with appropriate maturity steps (lifecycle) to assure the quality of the document content or to obtain a *good* document version.

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[1] Keeping good documents is done in a good change process which is outside the scope of this paper. The change process is discussed in [7].

1.4 Overview of current Research

This chapter is an exploration about how researchers are thinking about improving the Building and Construction process with special interest for efforts to obtain good documents.

Based on the assumption that without proper exchange of design and engineering data and ditto accessible libraries it is not possible to achieve major improvements in Building and Construction processes there is a lot of research and development going on in the information and communication technology, ICT. Examples are:

- The development of Building Information Model BIM [9];
- COINS, a Dutch initiative to handle, create and view 3D intelligent objects in a multi company, multidisciplinary project [10];
- Gellish, a common language for the exchange of information between different systems [11].

Modern PLM systems, as developed in industry, have a lot of technological possibilities like the lifecycle management of documents, complete with workflows. But if users do not know the processes they want to execute the system might end up as an expensive archive and failure costs will not drop. It was Shelburne [12, 13] who followed very consequently the path of "Processes first, tools have to follow".

Typical is the reaction of the commission Veerman reporting on the situation of the "Noord Zuidlijn" project of the City of Amsterdam. All advices for improvements are dealing with better communications and better cooperation between the stakeholders of the project. (Veerman [5])

Vrijhoef [6] is doing research in the supply chain of Building and Construction projects and reports savings of ten percent by an open and transparent co-operation of the project partners. A maybe more structured approach of Supply Chain Management can be found in Mathews [14] about integrated project delivery (IPD).

However these issues have only an indirect impact on the quality of documents and realised buildings and constructions are based on these documents. Things are going wrong because output documents from activities do not comply with the specifications or input documents on one or more places in the development process.

There is more to say about the quality of documents in industry. Guess [3, 15] reports that an average engineer is spending 40 to 60% of his time in interfering in activities which did not go right the first time. Wortman [16] states in his work about Six Sigma that about 75% of what is going wrong at realising the product finds its origin in design and engineering[1]. There is no reason to expect that things are better in Building and Construction.

Ahire [17] shows the importance of design management and process management for the product quality but does not come down to the level of documents. Coates [18] is coming closer to engineering, distinguishes a number of key elements to optimise engineering operations under which task management but doesn't speak about engineers product: the document. Eloranta [19] describes three main process lines, the business line, the product development line and the realisation or material line. Following Guess [3] one can argue that the material line always has to be a projection of the product development line so it is not an independent axis. This leaves us with a business line with

[1] If this is true there exists an opportunity to double the productivity of design and engineering and save 75 per cent of the failure costs.

business issues and a product development line with document issues as covered in this paper. Also Eloranta describes the important role of documents with their lifecycles, statuses and versions. Stubblefield [20] discusses that a document has to be authorised and shows the different worlds of creating engineering documents and the administration of documents. Saffadi [21] even adds another document lifecycle. It is an overall lifecycle from creation, in use until archived, but it is not a lifecycle of importance for the underlying study.

The lifecycle can be considered as a sequence of maturity statuses until and including released. More details on document naming, versioning and lifecycles are discussed by Pels [22] and Pels [23]

Two authors go quite far describing processes to get and keep good documents. These references are Guess [15] and Watts [4]. Both authors are discussing single company industries. The main difference with Building and Construction is that Building and Construction projects always are performed by consortia, so one is dealing with an extended enterprise.

Research to improve Building and Construction processes has different focuses. Popular are ICT topics and standardisation and also supply chain management.

It can be concluded that it is generally accepted that a document has a version and that a version goes through a lifecycle with phases called status. Also it may be concluded that the management of documents is considered important. Release processes are mentioned but rarely really worked out. Answers on why, what and how are not given. And there is certainly not much information about the requirements for an effective and efficient release process. This article will try to give some more detailed answers.

2 Release Process

2.1 A natural release process or the basic lifecycle steps

To discuss a release process of a document version means discussing its lifecycle.

Let us consider an engineer writing a letter to a lawyer, which is another professional in another professional environment, speaking another language. The letter first has to be written. After it is written it will be judged or the lawyer will understand everything that has been written as intended by the author. Eventually the letter is signed or authorised meaning the author, our engineer, takes his responsibility for the content of the letter. In the writing of this letter one sees three basic steps and related roles in the lifecycle of this letter:

1. Creation;
2. Judging;
3. Authorising.

The author of the letter fulfils all three roles. He is the creator, the judge and the authority that releases the document.

In a design and engineering process every activity is about creating and editing documents. In principle the document versions have to pass the same basic steps of create, judge and authorise. The only difference with writing the letter in the lawyer example is that the basic roles are fulfilled by different persons.

This natural release process differs from the common practice two step processes in Building and Construction as we saw before.

2.2 Other requirements for release processes

2.2.1 Quality and knowledge

Every product document is input for another activity. The quality of the content is also depending on the quality of the input used to create a document. Input documents need to be good. A Building and Construction process is a multidisciplinary, multi-company process. Normally documents are covering aspects related to different disciplines. Take for example a drawing of a wall. The architect is interested in form and location, the structural engineer in its strengths and the piping engineer in the size and location of a recess. It means the release process needs a number of reviewers covering all aspects of the requirement or document version to be good.

It is clear that the quality of the content of the document version depends also on the skills and experience of the author. Education and training however are outside the scope of this article.

It is also clear that in most cases the author only has partial knowledge of the product to realise. This means that the release process needs a practical mechanism to bring all available knowledge within the project, within the different independent parties, into the document version.

This available knowledge is supposed to be present as well with the reviewers of the document version as well with the colleague designers and engineers in the project. There is also knowledge accumulated in the collection of released documents.

2.2.2 Integrity of information

Wortman and Guess indicate the tremendous importance of the integrity of information[3, 16]. Guess[15] suggests an audit as a final check before release. Within the audit it is checked or all agreed procedures have been followed and if not the involved officers have to redo their jobs.

2.3 The development of an effective release Process

2.3.1 Introduction

A good release process will result in good documents and vice versa a relevant portion of flaw documents in the project is a sign for a bad release process. The commonly used two step document lifecycle in Building and Construction misses a formal judge or review phase and is quite often non-used or not properly used as we saw before in the mentioned examples.

Starting with the natural release process and taken into account the extra requirements a new release process will be developed.

2.3.2 Challenges

In order to create good documents the following issues have to be improved:

- Define a good lifecycle for documents in which they are created, judged and released;
- Define and organise a release process in which all available knowledge is used to create good documents;

- Define and organise a release process in which all required aspects are judged and approved documents are authorised;

2.3.3 Use of all available knowledge and concurrent engineering

Within the scope of release and change processes the topic is not the knowledge in handbooks or libraries but the topic is about people and the knowledge in their minds, so the knowledge and experience people have and the knowledge that is direct accessible to them.

How to bring this knowledge into the process? One way to do bring this knowledge in the development process is by using multifunctional teams as is discussed for example in Blanchard[1], Martin[24] and Reefman[25].

Today multifunctional teams (MFT's) are especially used in the phase of defining the architecture of the product or building the concept design. In a similar way multifunctional teams are used to make proposals for complex change requests [3].

But within the scope of the release process, in order to obtain the maximum available knowledge into the content of a document version, one wants to bring together the practical knowledge of all designers and engineers at different parties and different locations in their daily work. The idea is that you only can bring the knowledge and experience of all involved designers and engineers into the daily work as people can react directly on each other's work. This means to realise one of the aspects of concurrent engineering, concurrent mutual involvement in a structural way in the overall project [25]. This should happen as early in the work as possible because than changes are cheap, thus preferably before release!

Within the IPM® approach this is realised by introducing a fourth status in the earlier mentioned natural life cycle for a release process. This status is called "POST". In this post-creation phase early in the lifecycle, the document version is open for responses from colleague engineers in other parties and or disciplines. They might react with their experience and skills on the document version created that far. This is considered as an effective and practical method of bringing available knowledge into the project. It is a balance between informal and formal communication with as side effect more individual involvement in the total project, more fun and good for the project.

The document lifecycle becomes now:

- IN WORK (Creation);
- POST (Observation);
- UNDER REVIEW (Judging);
- RELEASED (Authorised and valid).

2.4 Process

So far the author has arrived to a four step document lifecycle, three natural steps regarding creation, judging and release, extended with a fourth step, observation to capture the maximum knowledge available in the project. In this chapter the execution of such a release process is discussed. A release process with the discussed four step life cycle is given in fig. 2.

2.4.1 Phase 1, creation of the document

The activity to create a document starts with an order. In the initial stage the document is only identified and has no version yet. When the engineer starts to create content the document gets its first version and the maturity status is IN WORK.

The engineer creates a drawing, model or any other document describing something of the product or building to be realised. On a certain moment in time the engineer considers the document mature enough to show to the colleagues of other disciplines. The author will promote the document version to the next lifecycle step “POST”. While the engineer continues the development of the document version the colleagues can observe the work done so far and give comments.

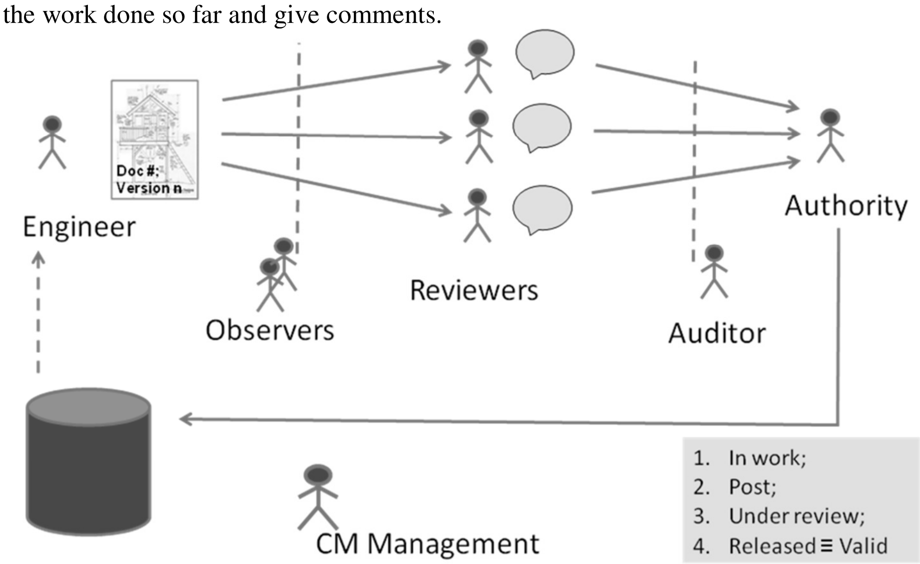

Figure 2 The proposed release process

When the document is ready it will be promoted to UNDER REVIEW to be judged. This can be done by the engineer but there is also an argument to let this promotion done by his manager as a kind of check or pre-review for documents involving many aspects or with a high impact on the project.

The document version starts with the status IN WORK. This is a kind of private situation, except the creator nobody can see this version. This looks logical, but it is not. It implies a lot of choices! For example the choice is made that the document version is made by one person and not a number of persons. Another choice is that before a certain maturity is reached nobody has any access to the document version other than the author. Other choices are possible for example that each document version in each status is readable for any project member.

2.4.2 Phase 2, observation of the document

The maturity status of the document or model is POST.

The objective of the observation is to stimulate the involvement of the single engineer in the overall programme or project to bring in his or her skills and experience in the development of the product or building. Seeing the work of the creator of the document version each observer can react from his point of view, with his or her knowledge. Giving comments is not obligatory neither is the creator obligated to do something with the comments. It is a controlled way of informal information exchange in the early stage of the process of document creation.

For example a structural engineer reacts to his colleague at the design office that with the current load on the structure the thickness could be 50 % and the wall would still be strong enough.

The Post phase is a situation “For information only”. No one is allowed to do anything else than comment on this document version.

Pels [personal discussions] argues that because the author of the document version is still going on developing the version and nobody is obliged to do anything it is also possible to have one status In Work in which all observers can see the document version and comment. The author of this paper argues that observation is a logically different status, as well informal from a communication point of view, no obligations, as well formal from a process control point of view, a formal request for comment. Furthermore the author of this article wants to take into account that Building and Construction is dealing with an extended enterprise so the observers of the document version will cross enterprise borders. A clear separate lifecycle status will be needed to formulate and agree procedures between the project partners. But still the other choice should be workable as well. More choices have to be made, like who should be assigned to be an observer, the choice of the author every engineer involved, might be impractical and not an attractive invitation to the invited individual to supply a real contribution. It seems practical to assign observers like reviewers depending on the aspects related to the document. The POST status will end automatically when the document version is promoted to UNDER REVIEW.

2.4.3 Phase 3, judging the document

The maturity status of the document or model is UNDER REVIEW

The document has to be reviewed regarding a number of aspects usually requiring specific specialists. For example the document version requires a validation on the dynamic behaviour of the structure and also a validation that it fulfils all requirements on environmental regulations and a validation that it can be produced within the available budget. The reviews may lead to adaptations of the document by the creator (of course in a new document version!) before it is accepted and validated to be good. The review is obligatory and the document version has to be approved or rejected. Disagreements have to be solved within the release process by a next level reviewer for example a design leader or the authority who has to release the document.

The review might be a process on its own. For example it might require a complete structural analysis to validate the strength of a building part.

The essential difference between observation and review is the difference between an informal advice and a formal validation. Consider that structural engineer doing a full structural analysis to validate the document version. Suppose he was one of the observers as well. In his role as an observer he would never execute a full analysis but instead he would, based on his skills and experience, give an advice like it was mentioned in the example of phase 2.

In case documents have to be adapted the creator starts to edit the document by copying the content of the document version UNDER REVIEW into a new version of the document which gets the status of IN WORK. The new document version will follow the release process from the start.

Again many choices have to be made for example who has which rights on which document versions and status. These choices are also depending on the organisation and contracts between the parties in the extended enterprise.

Several authors mention the importance of the integrity of the database amongst them Guess [3] and Wortman[16]. To assure this integrity it is advised by Guess to audit the process before a document version is accepted to be fed into the database as a released document version. The auditor confirms that all procedures have been followed in the correct way. If the auditor is not satisfied he will return the document to the responsible officers to correct their work.

Reviews on specific aspects are scheduled first and in parallel. If there is a design leader or other line manager involved they might be scheduled in series after the reviews of the parallel specialists. The auditor is the last reviewer before the authority.

The authority is in fact a special reviewer; he promotes the document version to its released status, confirming project responsibility for the released document version.

2.4.4 Phase 4 authorising or releasing the document version

After authorisation the status of the document or model becomes RELEASED.

The last step is many times just a formality but a very important formality because with the authorisation of the document the legal entity, e.g. company or consortium, takes full responsibility over the document version.

Again choices have to be made like:

- The document is available for all downstream activities.
- The document is accessible for all stakeholders of the project.
- The document version can only change within a formal change procedure.

2.5 Discussion of proposed release process for document versions

It has been discussed in the article that the used document statuses Draft and Final in Building and Construction are irrelevant in most cases and in case they are used in the right way it is just not enough, it misses the Review step.

The business reasons for an effective release process have been mentioned. But there is a social result too. On the job floor life is getting more fun, designers and engineers will have all the time to do the job they are hired for. They get good documents and are able to deliver the expected results in a shorter time. Via the POST status in the release process everybody on the shop floor is involved in the whole project, which also increases the fun in the job.

The importance of data integrity is taken into account by adding an auditor in the release process.

For document versions with only one relevant aspect to review, for example minor changes regarding just one aspect, the release process as described might be a little bit overdone. A fast track release process may do the job. In such cases one could follow a release process as proposed by Guess[3] and Watts[4] were the whole release process then goes along with the change process. Creation, judge and authorisation is done by two persons, the creator or author and an assigned user. In this case the authorisation is a delegated task; the responsibility stays with the project or programme management.

A PLM demonstrator, including organisation, roles and responsibilities with workflows for the proposed release process and also a change process conforming Guess[3] has been built at the University of Delft.

3 Conclusions

The objective of the study was to design a process to achieve good documents in Building and Construction processes meaning a quality assurance for process and content.

The objective is achieved by starting from the simple activity of writing a letter. It is concluded that such an activity is subject to a release process with three essential steps: creating, judging and authorising. These three steps are taken as the basic document lifecycle. All aspects related to the document version are reviewed in a structural way and the document version is properly authorised. The suggestion of Guess[15] is followed to add an auditor to the process to guarantee that all procedures have been followed as agreed. In order to establish a document version with maximum quality for its content, a fourth lifecycle step, for observation, has been introduced were all available skills and experience in the project will be accessed. It is a practical way of getting all available knowledge within the people in each document version.

Besides a confirmation that creating good documents is relevant for Building and Construction processes there was no reference found, discussing how to do that.

Creating good documents is not the complete story. The good document versions have be succeeded by good documents versions, meaning a qualified change process has to be implemented as well Reefman(2011)[7].

Further research has to be performed on the application of document release processes in Building and Construction. Measurements before and after structural implementation of appropriate release and change processes have to be done to quantify the achieved reduction of failure costs.

Acknowledgment

The authors want to thank Dr. ir. Henk Jan Pels (Technical University of Eindhoven) for his stimulation of the work, his intense discussions and advice.

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An integrated requirements elicitation approach for the development of data management systems

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Abstract: This paper describes a novel requirements elicitation approach in the fields of requirement engineering, cognitive engineering and product lifecycle management. The current growth of data-information-knowledge management systems for supporting product lifecycle processes in discrete and manufacturing companies has raised critical need of methodologies in requirements elicitation and analysis. Indeed it is important to consider generic issues as well as industry specific and business type's constraints related to quality-cost-time targets but also sustainability aspect in the development of new data management systems including bridge, hub and cockpit systems as the latest strategic efforts. The main objective is to define an adequate methodology for requirements elicitation and documentation, which provides the basis for conducting the cognitive work analysis, the functional and the technical requirements specification of such data management systems. This paper states briefly requirements elicitation techniques and approaches, and the description of a much larger research project in which the proposed method is being applied. Then the description of the integrated requirements elicitation approach steps for collecting and documenting end-user requirements at various abstraction levels is presented.

Keyword: requirements elicitation; data management system; cognitive work analysis; sustainable production; product lifecycle management; PLM.

1 Introduction

Nowadays the emergence of computer-aided tools and data-information-knowledge management systems for supporting the entire product lifecycle require an adequate and flexible method to elicit end-user requirements from a functional as well as a technical point of view. So far, computer-aided tools and information systems used all along the product lifecycle have been developed by considering competitive drivers such as efficiency, productivity and flexibility as the main targets. However the growing development of Web-services (Georgiev *et al.*, 2007) and the emergence of Web-based applications for mobile devices to support product lifecycle processes in discrete and manufacturing companies has raised further challenges to tackle. Indeed this highlights need in methodology for the specification of new kind of information system (*e.g.* information systems enabling monitoring and control data for real time decision making) (Sacks *et al.*, 2010).

At this stage, it is important to consider generic issues as well as industry specific and business type's constraints related to regular competitive drivers but also to sustainability aspect in the development of new data management systems including bridge, hub and cockpit systems as the latest strategic efforts (Howard *et al.*, 2006). In this context, this research paper describes a novel requirements elicitation approach – called *i*REA (*i*ntegrated Requirements Elicitation Approach) – in the fields of requirement engineering, cognitive engineering and product lifecycle management (PLM). The main objective is therefore to define an adequate methodology for requirements collection and documentation, which provides the basis for conducting the cognitive work analysis, the functional and the technical requirements specification of such new information systems. In section 2, this paper states briefly key requirements elicitation techniques and approaches, and addresses a much larger European Union funded research project in which the proposed approach is being applied. Finally the *i*REA steps for collecting and documenting end-user requirements at various abstraction levels, by introducing specific techniques and templates, are described in detail.

2 Research and industrial contexts

This section gives a brief overview on the research and industrial context in requirements elicitation for developing new data management system, in order to provide current challenges in this field.

2.1 Research overview

The requirements elicitation can be considered as the first and main phase of the requirement engineering process as a critical stage of information system lifecycle, which has resulted in many research efforts over the past thirty years (Loucopoulos and Karakostas, 1995; Saiedan and Dale, 2000). Requirements elicitation is therefore involved in discovering needs, capturing, gathering, and documenting functional and technical requirements from involved stakeholders. Loucopoulos and Karakostas defined this activity by considering the social and cognitive aspects in a systematic process, which promotes a better understanding and accuracy of what is needed (Loucopoulos and Karakostas, 1995). Among the many research techniques and approaches in this field, which have been reported and classified by (Zowghi and Coulin, 2005), it is still possible to identify challenge to tackle.

Indeed, from purpose-oriented (including scenarios, use cases, goals, etc.) (Haumer *et al.*, 1998) to viewpoint-oriented (Leite and Freeman, 1991; Kotonya, 1999; Sommerville, 2004; Al-Salem and Samaha, 2007) and collaborative approaches (Wood and Silver, 1995), researchers have tried to improve the accuracy and efficiency of the requirements elicitation process (Duran Toro *et al.*, 1999). To build these approaches, a lot of techniques have been used such as:

- Traditional techniques: including interviews, questionnaires, tasks analysis, domain analysis, etc.
- Cognitive techniques: card sorting, laddering, etc.
- Group techniques: brainstorming, workshop, meeting, etc.
- Contextual techniques: ethnography, contextual query observation, protocol analysis, apprenticing, and prototyping.

The key challenge is to ensure effective communication between various stakeholders (analyst and end-user) and a comprehensive investigation of tacit knowledge through various abstraction levels, in order to provide relevant and well-structured, and defined specification for traceability and processing (Montalbert *et al.*, 2009). This issue is reinforced by current research and industrial initiatives, especially in the development of cockpit system at the beginning of the product lifecycle (Hashemipour *et al.*, 2000).

2.2 Description of the EU PLANTCockpit project

The objective of developing a new methodology for eliciting functional and technical requirements is being required and addressed in the European Union funded research project called "Production Logistics and Sustainability Cockpit" (PLANTCockpit) related to the factory of the future issue in the Seventh Framework Program (FP7 FoF). Indeed, one particular objective of PLANTCockpit is to provide a central environment for monitoring and control of all intra-logistical processes in discrete and manufacturing companies. This therefore includes business (*e.g.* material availability) and technical data (*e.g.* resources status), transactional (*e.g.* shop floor orders) and historical information (*e.g.* downtime), alerts and events (*e.g.* material was not delivered), and Key Performance Indicators (*e.g.* yield rate, lead time, energy consumption, etc.) to name a few. To do this, this cockpit environment will be integrated to heterogeneous environments currently used from shop floor to production engineering levels such as ERP (Enterprise Resource Planning), MES (Manufacturing Execution System), SCADA (Supervisory Control And Data Acquisition), condition-based maintenance, energy management and other specific-purpose systems. In this way, the production supervisors and managers will have the required visibility and awareness on the right information to make well-informed decisions, in order to optimize plant logistical processes from a sustainability point of view. Based on this research challenge, the future central environment – considered as a sustainability cockpit – has to be specified and developed in a collaborative and integrated manner by fulfilling functional and technical requirements elicited from various companies in diverse domains. As a result, the following section presents the proposed approach based on these industrial and research contexts.

3 Description of the integrated requirements elicitation approach

3.1 Overall process description

In order to give an overview of the proposed *i*REA, an IDEF0 diagram is introduced, in which the several steps including input and output information, the associated technique and templates as control means, and the involved actors are presented. Figure 1 presents a static snapshot view of the input-output model and the related information flow. This proposed representation of *i*REA is hierarchical in nature and thus allows a top-down decomposition of each phase. Here, the proposed approach can be broken down into five steps partially based on the nested constraints levels proposed by Rasmussen et al. (1990), and listed as activity below:

1. Vision statement analysis (A1)
2. Work domain analysis (A2)
3. Control task analysis (A3)
4. Strategies analysis (A4)
5. Requirement specification (A5)

*i*REA enables the incorporation of the cognitive work analysis (CWA) in the specification of requirements for the future data management system (Sanderson, 1998). CWA is a formative, constraint-based framework for analysing complex work domains (Vicente, 1999). This aspect is inspired by ecological psychology's tenet that complex human behavior in operational settings can be usefully explained by analysing the complexity of their surroundings. It comes with a pre-existing process and a number of tools that focus on cognitive and perceptual aspects of information systems development. The purpose here is to highlight these techniques and suggest similar modelling tools that may be more familiar to analysts from a software engineering background. With the aim of providing a structured guidance on knowledge gathering techniques, the description of iREA steps is addressed in the following sections.

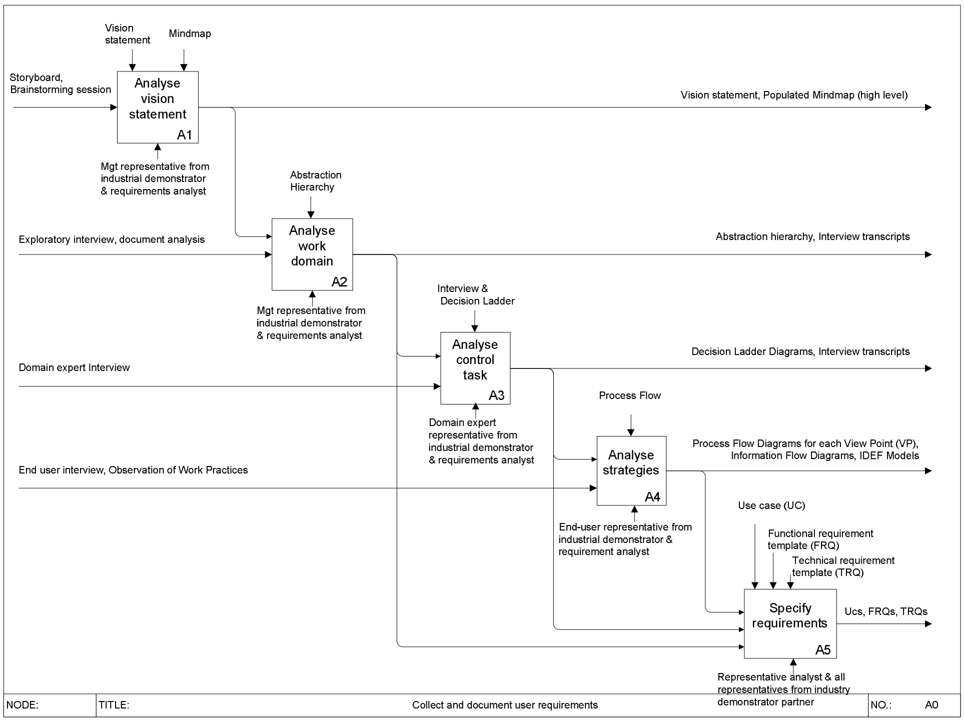

Figure 1 IDEF0 diagram of the *i*REA steps

3.2 Vision statement analysis (A1)

The vision statement stage describes the highest functional purpose of the future system by explaining the business need for the technology, its estimated impact and some means for evaluation. The vision statement facilitates the process of identifying a solid business need by calling out goals and what is needed to achieve these goals. This step also helps to describe the associated roles and their primary goals. This should describe potential end-users of the system in terms of their job specification and responsibilities.

At this stage, a network diagram is often used to help map and visualise these users, goals and interactions. The brainstorming technique is often used whilst populating the vision statement information and several sessions may be needed. In addition, a storyboard approach can also be taken to map out all of the above. The vision statement can be deployed through a Mindmap form, which is used as a modelling tool for this analysis stage.

3.3 Work domain analysis (A2)

Work domain analysis involves the development of causal models that clarify cause and effect relationships between an overall system, its subsystems and their constituent components. This model is a field description based purely on the environmental constraints imposed on a system that dictates its functionality. These may be physical laws, legal regulations (*e.g.* gas emissions) or management targets. A work domain model is event independent and defines the system purposes at multiple abstraction levels, but does not describe events or user actions carried out during work.

The first stage to developing a work domain model is gathering information about the system. The vision statement should provide enough information to start the investigation of the relevant infrastructures, control systems and organizations that support the work. Documentation gathering and analysis is usually an early step in the process, this may includes the study of org charts, training material, operations reports, CAD drawings, process diagrams, software manuals, technical papers, etc. Documentation analysis should suggest the reasoning of domain practitioners, leverage points in terms of opportunities and is useful in the attempt to construct knowledge models. This activity also provides the basic knowledge and vocabulary needed to be able to communicate with the target domains subject matter experts and end users.

Exploratory interviews with domain experts can be used to identify important high level goals and subsystems that support them. An unstructured interview approach is generally required during initial meetings, as concepts about system functionality are being formed and normalised. These interviews may be facilitated through mind mapping exercises (Buzan & Buzan, 1994). However, it is important to focus on the functionality of the whole system rather than the tasks of individual actors at this early stage of the analysis.

A number of different modelling techniques can be used to extract these causal relationships within a work domain. Abstraction hierarchies are a particular type of hierarchy that describes means-ends conceptual relationships. Representing a functional system in these terms highlights the cause-effect relationships that are necessary to conduct system diagnosis and decision support (Rasmussen, 1985). The number of levels of functional abstraction depends on the complexity of the system, but five levels have generally been found to be appropriate (Bisantz and Vicente, 1994). These levels have been described as functional purpose, abstract function, generalised function, physical function and physical form.

3.4 Control task analysis (A3)

Control task analysis identifies the information transformations that are required to control a functional system. While work domain analysis focuses on system constraints and causal relationships, control task analysis focuses on system events and information processing. It differs from other forms of task analysis in that it focuses on what and why information processing occurs rather than by whom and how. This approach is agent independent; in that it identifies the information processing that must occur without referring to whether this is conducted by a human or automated controller.

A modelling tool called the Decision Ladder is used to trace how this can occur (Sanderson, 1991). The document analysis conducted in the previous step should have provided a rich understanding of the functional purpose of the domain under study. In this phase we focus of how this functional purpose is achieved. Interviews with system users and owners are the most efficient means of gaining knowledge about system events and responses. A semi-structured interview process is recommended where participants are posed open-ended questions. Where possible interviews should be recorded and transcribed to allow for detailed analysis of the subject matter. Where this is not possible it is recommended interviewers work in pairs with one leading the questions and the other responsible to note taking. Sketching of process flows, decision ladders and interfaces by both interviewers and interviewees is encouraged, and these artefacts should be documented. The Decision Ladder can be used to model the decision-making process involved in controlling a system. In this way causal reasoning can be understood as a progression up through the decision ladder as an agent moves from skills to rules to knowledge based behaviour. The decision ladder allows an analyst to identify where different strategies need to be applied. While it may be possible to automate some of these strategies, the decision ladder identifies where the outputs of this information processing is required to understand the system state. This allows the analyst to identify areas with high cognitive workload and opportunities for developing artefacts (*e.g.* visualisations) to reduce cognitive workload and increase situation awareness. As with work domain modelling, control task analysis should be seen as an iterative process where early models are reviewed and repeatedly refined until they are considered to be valid representations.

3.5 Strategies analysis (A4)

While control task analysis defines *what* information processing needs to occur at a high abstraction level, strategies analysis describes *how* outputs are achieved in reality. As well as documenting current activities, strategies analysis can be used to identify situations where automated information processing or visual encoding can reduce cognitive workload for end-users. Workers frequently need to adopt new strategies to cope with unexpected events in their work. This is why observations and interview with end-workers is then critical. Interviews can be conducted with end-users to identify the strategies they apply to problem solving in their domains. Observing how work happens provides contextual information that may not be gathered or reported through interviews. This contextual information includes details about the work environment that are necessary to inform the design of end-user interfaces. Most modern work environments involve interaction with software and this can provide a useful starting point for analysis. An application walkthrough is an activity where a user demonstrates how they achieve a key task using their existing IT systems. It is recommended that a think aloud protocol is followed whereby the user talks through their thought process as they interact with the system. This allows the analyst to identify where expert tacit knowledge, which is not embedded in the user interface, is applied. It is advised to record these sessions for detailed post hoc analysis.

Process mapping is a well-established practice across many engineering disciplines. At a very basic level, process maps consist of a series of boxes and arrows are used to describe processes and flows respectively. These can be augmented with objects, decision points and other artefacts. While many forms of process mapping exist, differences generally relate to syntax, which is often customised to suit different application areas. Within the original cognitive work analysis framework, information flow maps are used to conduct strategies analysis. Information Flow Maps (IFMs) are graphical representations of the information processing activities and knowledge states of particular strategies. This modelling technique is not as well developed at the decision ladder or abstraction hierarchy but it still provides a useful method for formally describing the selection of a given strategy.

3.6 Requirements specification (A5)

3.6.1 Functional requirements specification

Requirements specification aims to integrate the output from previous phases of the analysis into a format that is interpretable to a software engineering audience. In the following sub-sections, three templates are introduced in order to model and document functional requirements.

3.6.1.1 Use case

The proposed use case diagram is used for capturing the potential functional requirements of the new data management system. It describes how the system should interact with the end-users for another system to achieve a specific business goal. Each field of the use case template is described below:

- **Use case ID:** is uniquely identified in conventional manner.
- **Use case name:** is defined by a descriptive name in order to facilitate identification.
- **Pre-condition:** is used to convey any conditions that must be true when a user initiates a use case. They are not however the triggers that initiate a use case.
- **Actor:** outside of the system that interact with the system; an actor can be a class of users, roles that users can play, or other systems.
- **Triggers:** describes the starting conditions causing a use case to be initiated.
- **Primary flow:** at a minimum, each use case should convey a primary scenario, or the typical course of events.
- **Post-condition:** summarizes the affairs state after the scenario is complete.

3.6.1.2 Viewpoint definition template

The proposed "Viewpoint Definition" template enables to map viewpoints related to end-users. This step will provide some useful inputs for requirements analysis stage, and later on for the definition on data management system views. Each field of the template is described below:

- **Viewpoint ID:** each viewpoint is uniquely identified in conventional manner.
- **Viewpoint name:** each viewpoint is defined by a descriptive name in order to facilitate identification.
- **Business domain and impact:** domain related to the product lifecycle where end-user is involved and impact that the implementation of the system will have on business practices.
- **Purpose (needs and goals):** business needs and goals to be achieved.
- **Actor:** person and/or system who will be involved.
- **Role:** describe the role of the actors.
- **Role relationships:** relationship between the different roles and their individual contribution to the business needs as stated above.
- **Related requirements:** allows to link viewpoint with requirements.

3.6.1.3 Functional requirement template

Following the definition of viewpoints, and the whole CWA process, a functional requirement table is described to provide a full understanding, and to help functional requirements to be expressed and structured in a fixed and reusable form. Each field of the template is described below:

- **Requirement ID:** each requirement is uniquely identified in conventional manner.
- **Requirement name:** each requirement is identified by a descriptive name.
- **Version and date:** describe the current version number and date of the requirement definition.
- **Author:** contains the name of the author of the current requirement version.
- **Category:** characterizes the area of requirements: business model, system, etc.
- **Source:** contains the authors organization, *i.e.* end-user, customer.
- **Purpose:** states why the requirement is necessary to achieve business goals.
- **Description:** describes what the system shall do.
- **Specific data:** holds a list of specific data associated to the relevant concept.
- **Time interval:** indicates how long information about the concept is relevant for the system.
- **Comment:** contains additional information about the requirement that cannot be fitted in previous fields.
- **Related requirements:** enables the link of current requirements with others.
- **Domain instance:** allows knowing if the requirement can be considered as generic requirement.
- **Classification:** indicates how the requirement is important for end-user in terms of priority and difficulty.
- **Status:** holds the requirement status in the validation process.

- **Concerned VP:** allows to link requirements with viewpoints.

3.6.2 Technical requirements specification

The objective of this step is to provide guidelines to document technical requirements in consistency with the specified functional requirements, but also with CWA outputs. It aims at providing a state of the art of information systems and interfaces used in the end-user environment (*e.g.* manufacturing plant). This step is performed to allow the interconnection of the new data management system with all relevant existing systems. To ensure this, a template has been proposed that captures the following information:

- **Identifier of the technical system:** each system is uniquely identified by way of ID convention.
- **Name of the technical system:** the name with which the system is usually addressed should be put here, to allow re-identification in other any use.
- **Allocation in the automation pyramid:** it needs to be specified what role the system fulfils in the automation pyramid (*e.g.* if it is ERP, MES or SCADA).
- **Provided interfaces:** in order to gather information stored in the system, any interface for data exchange on a technical level provided by the system needs to be mentioned and specified.
- **Semantic information (function in the process):** the semantic information is the description of the information stored in the described system. This description needs to be exhaustive and needs the most care, because it sets the field for later integration.
- **Associated requirements:** allow to link with functional requirements.

Based on this, it is necessary to go further through the future application of the information system. Indeed, the definition, the objectives, the functionalities, the involved actors (externally and internally), the physical components as well as the software/support-systems of the application have to be studied to provide a complete documentation of technical requirements. Due to space limit, this part will not be described in this paper.

4 Conclusion and future work

In this paper, an integrated approach for requirements elicitation called *i*REA has been proposed and described in detail. The main objective of *i*REA is to provide a systematic approach to specify and document functional and technical requirements for new information systems such as bridge, hub and cockpit considered as the latest efforts in engineering. *i*REA incorporates a cognitive work analysis in order to facilitate the emergence of tacit knowledge and therefore enabling an accurate and detailed specification of requirements. A set of steps including techniques and templates have been addressed in this paper. To illustrate the feasibility and the relevance of the proposed approach, future work will address its application through the PLANTCockpit project with the specification and development of a sustainability cockpit.

Acknowledgment

This research activity is part of the European Union funded project called "Production Logistics and Sustainability Cockpit" (PLANTCockpit) in the Seventh Framework Program, Factory of the Future, Information and Communication Technologies. The authors would like to thank all PLANTCockpit partners for their collaboration and the European Union for their financial support.

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Traceability of Engineering Information Development in PLM Framework

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Abstract: The work reported here builds on the framework for engineering information development traceability by discussing the strategy for traceability implementation within product life cycle management (PLM) environment. The four key processes in the complex product development practice (requirement-, change-, characteristic-, and decision management) have been considered in more details as a basis for the development of the approaches for traceability implementation in PLM environment. The traceability records with a goal to integrate process and product information that is fragmented across different information objects managed by PLM environments have been selected as backbone for implementation. Two possible approaches, scenario- and agent- based traceability have been proposed and evaluated. Research and development questions for the further steps in TRENIN (www.trenin.org) project progression have been identified and described.

Keyword: Engineering information, product lifecycle management, scenario based approach, agent based system, TRENIN

1 Introduction

In order to master challenges of the modern manufacturing paradigm and confront with the challenges of the complex products and services, companies have recently provided new approaches for reusability, adaptability, and variety of products, services and engineering information. The importance of engineering information is underlined by the fact that product lifecycle viewed as chain of information transformation processes both consume and create large amounts of information as they proceed [1]. During the different stages of the product lifecycle different participants will acquire information from many sources, such as handbooks and design guides, catalogues, journals, books, training courses, previous projects, discussion with colleagues and customers, user and service guides, disposal reports, etc [2]. As the product lifecycle proceeds, engineering information will be used to document the decisions taken, describe potential limitations of existing solutions or their suitability for adaptation, and to identify what further information is needed. Throughout this process, the information will be evaluated and recorded by members of the product lifecycle team in a variety of formats, such as sketches, drawings, notes and meeting minutes. In order to support the product lifecycle as it progresses, a proportion of this information will be formally recorded in technical reports and other engineering documentation, such as CAD models, production drawings, calculations, installation instructions, etc. It can therefore be argued that the efficiency of the product lifecycle process is highly dependent on the effective utilisation of this existing engineering information.

Traceability of information provides the basis for assessing the credibility of engineering information, its better understanding and making judgments about the appropriateness of its use for a particular task [3]. Traceability has been considered as a quality attribute and many standards governing systems development require the creation of traceability procedures. In order to fully understand an item of information it is necessary to know something about the circumstances in which it has been developed and recorded. Currently there is little provision for acquiring, capturing and delivering with the engineering information, the information that provides its development context, and few tools to support this process. In addition, little is currently understood about the requirements for engineering information traceability in product design and development environment, and there are few methods by which effective traceability can be ensured [4]. The work reported here builds on the **TR**aceability of **EN**gineering **IN**formation - TRENIN (www.trenin.org) framework for engineering information development traceability by discussing the strategy for traceability implementation within product life cycle management (PLM) environment.

2 PLM state of the art

As Stark [5] postulates, PLM is the activity of managing a company's products and information about products across the complete lifecycle, from the early stages of conception to the final disposal or recycling of a product. As a comprehensive business tool, PLM involves the fusion of many traditional engineering disciplines such as computer aided design (CAD), computer aided manufacturing (CAM), and computer aided process planning (CAPP) with many traditional management disciplines such as lean manufacturing and six sigma quality control, supply chain management (SCM), and enterprise resource planning (ERP) [6].

The fusion is made possible by the rapid advances in computer, information and communication technologies. PLM in general, is today considered as an instrument for enabling the company to provide an additional value from their information to the customers and thereby gain a competitive advantage over their competitors [7]. PLM strategy is usually followed by information technology that allows faster, cheaper and better conception, invention, feasibility, testing and deployment of products. PLM allows significant improvements to the quality, cost, life, reliability and environmental implications of existing and new products. PLM allows seamless creation, training and deployment of products and information with embedded mechanical, chemical, electrical, computer, intelligence, and communications hardware and software.

The following list shows one way of classifying the functions of the PLM environment (Table 1): product data management (PDM), product and process definition, configuration management, customer-oriented collaboration, visualisation/viewing, data exchange, definition and management of the product lifecycle processes, project and portfolio management, system integration, etc.

Table 1 Functionality relevant for traceability issues that currently exists in engineering tools

PDM	CAD	OFFICE TOOLS
• Project management Document versioning management • Workflow mechanism • Engineering change management • Search/querying engine • Reports generator	• Feature tree (structure of the CAD model) • Associatively links between assemblies and parts • File versioning • Product 3D model characteristic management	• Track changes mechanism • Document properties management

Collaborative processes and technologies have dramatically improved the value of PLM systems that help companies better manage product information. But, in the same time many companies still suffer from diminished innovation and product development capabilities because of fragmented, disjointed information. The preset practice of recording the outcome of the product lifecycle process is for highly formalized model of the product to be produced, in the form of conceptual sketches, calculations, computer-aided engineering models, bills of materials, engineering change orders, maintenance instructions, etc. However, the detailed process, activities and rationale by which the product has been designed and created, and engineering information has been developed, are recorded in poorly accessible informal manner (if at all). Consequence of such practice is lack of engineering information origin understanding and danger of mistakes during existing information retrieval, adaptation and integration.

3 Traceability of engineering information development

The different stakeholders in product lifecycle process would like to have traceability carried by traces of the product lifecycle routes, because they want to reuse existing engineering information along sources, references, evaluation, meaning, reasons, arguments, documentation, choices, critique, consequences [4]. They would like to leverage all relevant information no matter where it originated, no matter what its format, and no matter where it resides in order to help their organization innovate, compete, provide service and grow. Ability to trace engineering information development becomes prerequisite for better information value understanding and recognition and act on the importance of information quality in product lifecycle process [8].

Little is currently understood about the requirements for engineering information traceability in product lifecycle and there are few methods by which effective traceability can be ensured. There are a number of methods and tools which contribute partially to the traceability of information development in general, but the emphasis here is either on description of the product data management (PDM) or project/workflow management rather than the explanation of development and rationale on information antecedents.

Traceability should assist in understanding the relationships that exist within and across product lifecycle information like requirements, design details, component description, production specification and maintaining procedures. These relationships help engineering designers to understand the rationale behind the design procedures during product development. The need for maintaining traces among information objects to support change management in product development is well documented in our previous publications [3], [4]. Literature also describes the adverse impact of poor traceability practices on project cost and schedule. Decrease in system quality, increase in the number of changes, loss of knowledge due to turnover, erroneous decisions, misunderstanding, and miscommunication are some of the common problems that arise due to lack of or insufficient traceability knowledge .

Traceability records should help in maintaining a semantic network in which nodes represent information objects among which traceability is established through links of different types and strengths. The simplest traceability tools that have been found in engineering practice during the interviews with our industrial partners are purely relational (i.e. in the form of spreadsheets or personal notes) and do not systematically distinguish different node and link types. They are suited only to support simple traceability practices for personal use and provide limited support for information dependency analysis. In our project, this lead to the development of a traceability records with a goal to integrate process and product information that is fragmented across different information objects managed by PDM/PLM environments.

4 Key processes to be supported by future traceability methods and tools

Little is currently understood about the engineering information evolution traceability and there are few methods by which effective traceability can be ensured [9]. Different research groups approach to the many parts of the traceability issue through perspective of knowledge integration [10], communication, handling complex dependencies between requirements and components [11], task-specific management [11], ontological retrieval of the unstructured documents [12], traceability schemes for integration of the product and process knowledge, appropriate information flow achievement [13] and architectures of the information search and retrieval systems [14].

In addition, there are no existing tools that support achievement of the full traceability of engineering information evolution in product development. Currently available PDM/PLM systems support information exchange between product developers, especially in the later phases of the engineering lifecycle which is characterized by more deterministic and well-known processes. However, they lack essential capabilities for the management and use of product information. Some recent research efforts try to extend the capabilities of PDM/PLM systems for product information traceability during the product development phase [15]. The key issue with the traditional traceability approach, in particular from the point of view of industrial applications, is that it is labour intensive, both for the product information-engineering specialists as well as for those whose information they are seeking to acquire. This PDM/PLM repository in practice is usually limited to the storage of product data and documents. It does not offer support for the recording and management of the associated work.

In order to recognise key issues for the traceability records specification, modelling and implementation, we have decided to consider in more details the four key processes in the complex product development practice as a basis for further development of the new approaches for traceability implementation in PLM environment.

4.1 Requirements traceability

Requirements are the subject of an extensive body of literature in the information systems domain. Some of the work from this domain has been investigated with a view to making recommendations for traceability of the requirements in engineering design [16]. The following definition sums up the general view of the requirements traceability [17]: "*The requirements traceability is the ability to describe and follow the life of a requirement, in both a forward and backward direction, i.e. from its origins, through its development and specification, to its subsequent deployment and use, and through periods of ongoing refinement and iteration in any of these phases.*". In requirements definition phase it is important that the rationales and sources of the requirements are captured in order to understand requirements evolution and verification. Modifications during design appear e.g. if the requirements evolve or if the product is developed incrementally. During design phase requirements traceability allows to keep track of what happens when change request is implemented before a product is redesigned. Traceability should also give information about the justifications, important decisions and assumptions behind requirements. Test procedures on prototypes can be traced to requirements or design and this kind of traceability helps to design and modify test procedures. Modifications after the delivery of the product will happen due to various reasons (e.g. to correct faults or to adapt the product to a changing environment).

4.2 Changes traceability

To implement an engineering change request, change management strategy helps to identify necessary changes and understand the impact of changes. In general, the objective of different change management practices is to ensure a systematic development process, so that at all times the system is in a well-defined state with accurate specifications and verifiable quality attributes. Change management helps in the management, control, and execution of change and evolution of product, while traceability usually helps in managing dependencies among related artefacts across and within different phases of the development lifecycle [18]. In vast majority of organizations, these two practices are implemented in isolation. The lack of knowledge about how the process and product information are related makes it difficult to understand different viewpoints held by various stakeholders involved in change process and estimate the impact of changes, thus hindering change management and adversely affecting the consistency and integrity of systems. Without the capability to acquire and trace engineering information development, it is very difficult to incorporate modifications in the system. Therefore, change management should not only help manage changes to products of development (product knowledge), but also help trace the effects of the changes on other information entities (dependencies) and the reasons behind such changes (e.g. rationale) to maintain consistency among the various information entities.

4.3 Characteristics traceability

The definition of key product characteristic is one of the gifts of automotive manufacturing to all other kind of production. It is quite impossible to cost-effectively measure every possible characteristic of a given product. However, it is possible to define the most significant characteristics as key product characteristics (KPC). For example, the front of an instrumentation cluster may have significant appearance requirements, but is usually not necessary that the back of the product (invisible to the operator) have the same level of appearance quality. Hence, the front appearance and its definition is a key product characteristic. A KPC is a feature of material, process or part where the variation within the specified tolerance has a significant effect on product fit, performance, service life or manufacturability [19]. A KPC should be identified only after determining a significant benefit exists from controlling the characteristic to assure that the feature is at or very close to the specified value. KPC is usually identified as a part of the product development. Once a KPC has been identified, variation management activities must be performed until the process or processes that influence that characteristic are in control and process capability has been established. Appropriate traceability methodology for the key product characteristics should be implemented to assure continued performance of the products life cycle process.

4.4 Decisions traceability

In complex group decision and negotiation (GDN) activities, the participants access and use information about the problem and solution domains, which is stored in a variety of information sources such as spreadsheets, meeting minutes, design documents, etc. Seamlessly linking such information fragments spread across organizational work processes and tools will be very helpful in supporting GDN activities [20]. Creation of such networks by seamless integration has been attempted by many tools handling explicit, codifiable content (e.g., workflow tools, project management systems, collaborative systems, intranets, and data warehouses) and those that enable sharing and distribution of contextualized information content (e.g., digital whiteboards, case-based reasoning tools, multimedia channels, annotation tools, and concept mapping systems). One of the common problems in facilitating integration of information objects to support collaborative product development is that the stakeholders involved do not have adequate guidance on what kind of information elements should be integrated, and how the integration should be structured and used. Traceability, defined as the ability to describe and follow the life of a physical or conceptual thing, addresses these challenges by providing semantic and structural guidance to information objects integration. We could argue that integrating information fragments used by various stakeholders by providing traceability among them will increase the effectiveness of GDN activities performed during the product development process. Information objects traceability network can be defined as a semantic network in which nodes represent different information objects among which traceability is established through links of different types. Such a network facilitates the understanding and communication of the context in which group decisions and negotiations are carried out and help in monitoring the repercussions of changes in the underlying context.

5 Traceability implementation approaches

Based on the extended literature overview and discussion with research and industrial partners regarding the support that is expected from traceability implementation in engineering working environment, two possible approaches have been recognised:

- User predefines what exactly and how would like to trace in particular episode – **Scenario Based Traceability** approach (**SBT**).
- System is automatically or semi automatically tracing everything related to the information objects life continuum and enable users intelligent search among this records – **Agent Based Traceability** approach (**ABT**).

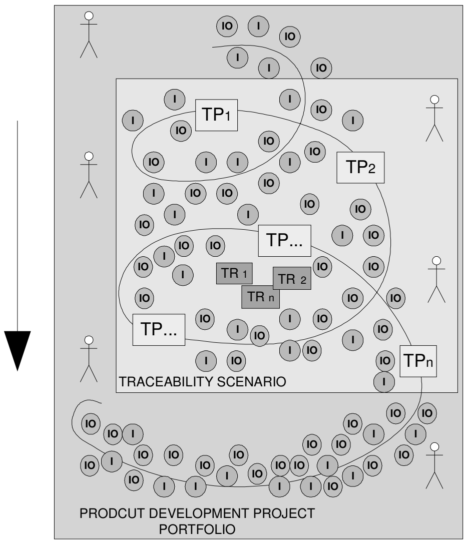

Figure 1 Scenario based traceability (SBT)

Scenario Based Traceability (SBT) approach is developed on some presumptions about information objects in product life cycle. Information object are characterised and described by different attributes like format, purpose, life continuum availability, content, form, versioning, status, responsibility, source, identification, fragmentation, links, etc. Traceability scenarios therefore should cover specific time interval in space-time continuum of the product lifecycle process. In that continuum, scenarios define set of the traceability points (TP) representing key events important for traceability of engineering information development. For each TP, scenario should define the structure of the traceability records (TR) that maps state change for the key engineering information that should be captured by proposed scenario (Figure 1).

Traceability record is defined as a record of the information objects changes and development including attributes, links and procedures that controls TR in particular TP. Traceability record is imagined as a „glue“ for the information content that it maps. Examples of the state change that could be recorded as a TR are: initialisation, use of content, semantic relation of the information objects and their fragments to other information objects, creation of the traceability record, etc.

Agent Based Traceability (ABT) approach was built around idea of extending existing PLM environment with intelligent agent technology in order to enable autonomous traceability actions necessary for traceability execution. The main ABT schema is presented on Figure 2. The core of the idea is traceability engine (TE) that, based on the specific events related to the PLM environment and PLM information objects, executes "intelligent" agents responsible for traceability tasks related to specific event. Agent management is done by agency is responsible to select right agent from the agents' pool and based on the description of necessary traceability behaviour executes it. That sequence result with traceability record in database. The main idea behind this approach is that current state of the PLM information object is a superposition of initial state and changes over the time. Therefore, the ABT traceability table will contain records of the every change of the PLM information object (including content, attributes, links, etc) and what is especially important, context of the change provided automatically or by help of human user involved in traceability process. The meta-data is a meaning for specification of the information or information fragments that will be recorded by ABT.

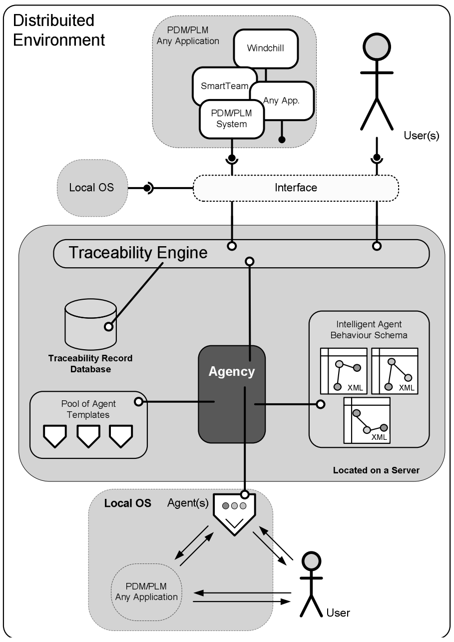

Figure 2 Agent based traceability (ABT)

After further development of the two approaches and discussion with potential users from industrial practice, the concepts like traceability record, traceability object, traceability point, and traceability engine have been clarified. The main advantage of the SBT approach is contextual richness while ABT records more information that could be, in a perspective, base for advanced automatic reasoning on traceability routes. The main problem with SBT is need to predefine all the possible traceability scenarios that could be of interest for different stakeholders in product lifecycle process, limitation on richness of available information and lot of manual work and interaction by the user. The problem of the ABT is formalism of the engineering information that should be fully respected in order to implement intelligent agent system, scalability of the potential and semantically rigidness needed. It was also recognised that TP in SBT could suit to events in ABT. TR that was imagined as a static list in SBT could be seen as a simplification of the agent and ABT traceability table that is more dynamic. SBT is limited by start/end time moment, and ABT by baseline in PLM.

Even though the two approaches have shown differences, the team finally concluded that would be smart in the further development to consider how two approaches could benefit from each other and be merged in single TRENIN architecture proposal. The key decision for the further development could be summarised as follows:

- **TRACEABILITY POINT** could be seen as an external EVENT that should be related to the product development process like workflow in PLM, and not only to the information life continuum activities. Research and development question that arise from this decision is about granulation of the engineering process and engineering activities that should be considered.
- **TRACEABILITY RECORD** instead being the pure static list of the information objects and hyperlinks between them should be more "intelligent" and dynamic container of the traceability elements, information and links semantically enriched in order to provide the context of the informational content development. The research and development question that should be answered in further research and development is about structure and properties of the smart traceability records.
- **TRACEABILITY ENGINE** should extend pure records of the information objects' state increment with context of the changes in order to engineering information be more useful for understanding and reusing. The research and development question from this conclusion is about development of the

vocabulary or ontology for the information objects development context description.

- **TRACEABILTY FRAMEWORK** should be implemented independently from PLM system since it has to be integrated with different types of the document management, file management, engineering data management and product data management systems that are currently used in engineering environments. The research and development question that should be answered in further development is about architecture of the traceability framework and integration with PLM functionality.

6 Conclusion

Consideration of the strategy and possibilities for the traceability implementation framework within product life cycle management (PLM) environment, has led closer to fully specified TRENIN implementation architecture. The following progress has been made:

- Identification of the shortcomings related to traceability functionalities in existing engineering tools, with focus on PLM systems.
- Key processes related to the complexity of the product development context to be supported by future traceability methods and tools have been identified and explained in cooperation with industrial partners.
- Two different traceability implementation approaches have been proposed and evaluated.
- Research and development questions for the further steps in project progression have been identified and described.

It is expected that further implementation of the TRENIN models and methods in PLM environment will enable semantic and structural guidance to full engineering information objects integration and smarter utilisation during product life cycle.

Acknowledgment

This paper reports work funded by EUREKA E!4911 TRENIN project (www.trenin.org) and Ministry of Science and Education of Republic of Croatia.

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New Product Data and Process Management – A Case Study of PLM Implementation for Formula Student Project

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Abstract: New and continuous product development requires a systematic approach in organizations. Data capture and management reduces the risk of failure in new product introduction and development. Lack of information and communication among project members can lead to an overall poor result or huge losses in time and cost. This problem is more evident if no personal contact exists in the development time of project or product. A systematic information management approach facilitates knowledge transfer between previous engineers to the new ones who never meet. PLM offers a unique opportunity for individuals within the projects to manage and communicate the project data resulting a well organized collaboration with minimum confusion. In this paper different aspects of PLM implementation are studied and applied on a case study that is Formula Student project. Lessons learned and benefits of this work, applicable to small projects that are typical of SMEs are highlighted and discussed.

Keyword: PLM, New Product Development, Digital Manufacturing, Data and Process Management, Formula Student

1 Introduction

Companies have different methods of collaboration both internally and externally through design, manufacturing, verification and assembly of products. It is always a challenge for companies to control and manage data that relates to their products and/or services. Companies that are more involved in New Product Development constantly face difficulties in keeping and reusing data in order to process it again into the next generation of their products. This is because until recently there has not been a systematic and standard method to follow, especially for small to medium sized enterprises (SME).

The variety of languages and formats and the existence of distributed objects such as CAD files and parts have driven businesses to create Product Data Management (PDM) tools that have the ability to support different hardware and operating systems. These tools allow CAD designs and parts to be updated based on the changes in business requirements [1]. PDM systems collect requirements, functions, concepts and part structures as well as property models and store the whole product structure, variants, revisions, documentations and CAD models in an available and secure environment. PDM systems can almost fully support micro level processes on the administrative models like version control and Change Management [2, 3]. However, these systems only offer limited support in collaboration and design processes in engineering information such as geometric models, bill of material (BOM) and finite element analysis. They cannot be implemented as a system to map functions and components of the products in the design phase [4].

The need to go further in managing data with regards to products and engineering information existed until the emergence of Product Lifecycle Management (PLM) systems in the 1990s. The aim of PLM systems is to cover all aspects of products rather than just engineering data that are normally handled by PDM systems. PLM systems enable users to support Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), Supply Chain Management (SCM) as well as tasks done by PDM systems. Capture, support and reuse of knowledge throughout the lifecycle are the core processes of PLM systems [5, 6].

The breath and width of PLM concept can include projects of large multinational organizations down to single and small company based. PLM implementation for small projects is typical of what can be seen in SMEs. In this paper the PLM concept is implemented for managing the information of a small scale case study project to facilitate the design processes based on classification, and information retrievals. The project team included 14 members who were working on a continuous product development project. The project covers all aspect of product data from design, manufacture and use of a Formula Student (FS) racing car. The main challenge here is identifying the users' requirements and implementing a data management system that can contain the project information in a systematic and easy to use way.

2 PLM Systems Overview

Large industries such as automotive, aerospace and shipbuilding have used CAD and PDM systems in the past to design and develop their products and drive them to have distinctive suppliers to support their needs. As products become more complex in terms of design, manufacture and service a wider range of suppliers and partners for engineering activities is required [7]. Management of high volumes of files and data from the products, on the one hand, and integration and collaboration with suppliers, partners, manufacturers, sales, services and customers on the other is the task performed by PLM systems. PLM is often associated with PDM. PLM is believed to have a greater emphasis on process issues rather than product issues [8]. Fundamental process in PLM can be interpreted as manufacturing and operational phases, whereas the essential requirement for PLM is workflow control during product lifecycle. It is believed that internal factors like customer intimacy, product innovation and process operation excellence, and external forces such as environmental issues, especially for products with a global market, are drivers to move companies towards PLM systems [5].

PLM system has numerous functional benefits for the internal and external communications in companies. Figure 1 illustrates that 21% of engineers' actual time in companies is spent on the jobs that were done before in the company [9]. This high percentage of rework in the companies can be resolved by having a single system capable of keeping all process related information in companies. Another time saving that can be achieved via PLM solutions is information sharing up to 24%. The challenges here include data compatibility and real time responding in disparate locations. This is not in the favour of large organisations that have different design teams and offices across the world. The real time communication allows the processes to be performed more quickly and information related data to be captured simultaneously in a single database system.

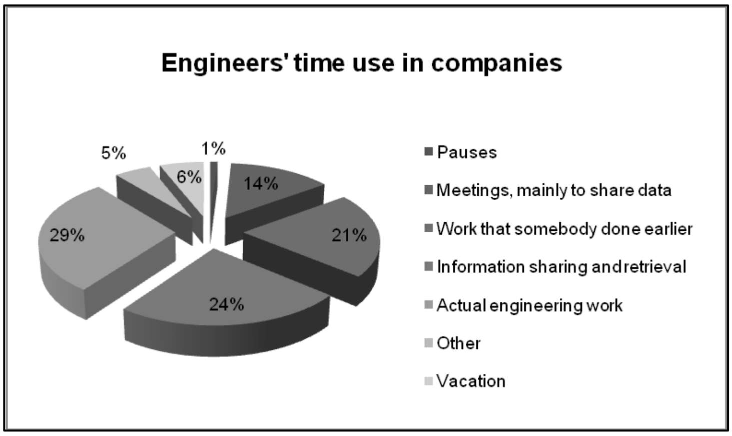

Figure 1 The engineers' use of time

It is clear that reusing the design reduces development costs and time. Research reveals that 90% of new products are not genuinely new [10] and that there is an urgent need for manufacturers to take control of design processes. For example in the case of automotive industries similar car models may have different body style with the same chassis and power train to customise the product for different regions [11] or models may even be presented as a new generation or product with minor changes. In the reuse design process the revisions of finished product design might be used as a new idea for offering a new product. For example it can be possible to manufacture lighter airplanes with better quality [12] than existing ones but the overall expenses can increase significantly. With progress in technology and advanced materials historical design data can often be used in product development.

Products have different meanings from the view point of different sectors. For instance manufacturing people believe that demand from the market is necessary before the imagination in order to realize the concept of the product (Figure 2). Detailed design is embedded in the definition; production in realisation, use of the product needs support and maintenance, and after use is the disposal and retirement phase [13, 14]. PLM systems are trying to manage all processes from the view point of anyone who is involved in the product development. The span of the PLM is from the raw materials to dealers, suppliers, designers, manufacturers, sellers, customers, service and maintenance, and recycling.

There is much research on developing and integrating more Digital Manufacturing (DM) into the design phase of products. It seems that the basic requirement for bringing DM and design into the independent process is the management of the product, process and resources that are the focus of the PLM systems. Cost optimization in the process of DM is possible by creating the various parts (BOM) that make up the final product [15]. The principle of Concurrent Engineering is based on successful collaboration tools that enable designers and manufacturers to act as a team effectively in order to turn ideas into successful products. Research shows that more than 70% of the manufacturing cost determined is in the conceptual stage, not in the manufacturing process itself [16], and supporting DM in different aspects of design can potentially reduce the cost of manufacturing.

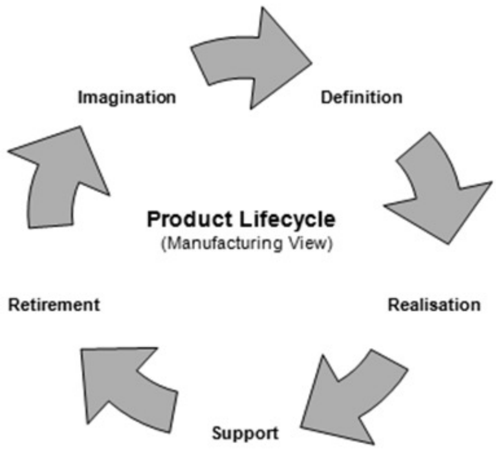

Figure 2 Product lifecycle from manufacturing point of view

Product development is in fact the process of introducing change in a product. Change can be necessary and can happen in various aspects of a product or a process including configuration, design requirement, or documentation. Change management may not be very visible in small organisations where people are working at the same station or workshop. In small projects like FS project in many cases design and manufacturing processes are performed only by one role. Here it is not a difficult task to manage the change in product as the person responsible for mentioned role can distinguish if the change in design adds any value to the project in the manufacturing stage for example. The other issue is that the designer of parts or assembly can ask colleagues in the manufacturing area whether a proposed change has any impact on other processes or parts. If the impact is negligible or controllable then they would implement the change otherwise the proposal for change will be ignored. It is therefore crucial to capture, analyse, validate and store knowledge of all the above processes for later use.

3 Case Study

Formula Student Competition is a yearly event organised by the IMechE (a professional society representing mechanical engineers in the UK) in partnership with many industrial companies [17]. All the universities at national and international level are invited to take part in this competition. The publicly available rules and regulations of the competition are set by the IMechE organisation. Warwick Formula Student (WFS) is one of these teams who take part in the completion regularly.

In addition to the general product data, for WFS team it is necessary to capture, analyse and reuse information related to late delivery and quality problems. This can secure a better outcome especially for the next year car and can be achieved by creating a precise data management tool. In order to implement such system effectively in the project it is crucial to have a close interaction with the project team to understand the team's requirements. Following this a structure for the team should be configured to be then used as the basis for the structure of data. This enables the team members to work in a better condition and ensures the project is constantly on target.

Figure 3 CAD design of WFS racing car

The aim of running FS project from the academic point of view is to introduce the real life situations to students and make them familiar with engineering challenges in design, manufacture as well as business aspects in the automotive industries. During the year the students will become familiar with many processes in projects such as decision making, team working, time management, marketing, project management and so on. In a nutshell students learn how to turn theory into practice.

3.1 History of WFS

Warwick University has taken part in the competition for the past 10 years with a team of between 12 to 19 student members in each year. The reason to have different number of students in the team goes back to their capabilities, work experience and background. Lack of consistency among the teams in terms of number of members and expertise is considered as one of the reasons that the team was unable to achieve high rankings within the past few years. Up until 2009 the highest overall ranking for the team from the start of their participation in the competition was 23rd.

3.2 Case Study, WFS Project in 2008/09

The team was formed by 14 final year engineering students for 2008/09 entry. Most of the members have different industrial work experiences. Due to lake of a systematic approach the variability in the number of students in the team in each year resulted in the team to adapt different type of structural roles and tasks. As part of the competition the team needs to analyse, design and manufacture up to 900 components. For the majority of these components the design or even the components manufactured in the previous years are used. Therefore only a handful of components need to be redesigned that equates to further improvement of the previous years' design. The team has access to PDM enabled software for digital design and simulation purposes for identifying optimal solutions. One of the initial decisions for the team is to decide what parts can be manufactured in house and which one can be outsourced. There are parts that have lower cost to manufacture rather than outsourced. These parts are designed and manufactured in WFS workshop.

3.3 Roles and Organisation in FS Project

Lack of an effective approach for organising and reusing design data in WFS has contributed most in the motivation of implementing PLM in their project. The racing car is in effect the key product that has constant improvement year on year. The importance of structured data management becomes more evident when there exists no in person contact between members of two consecutive years to exchange information. The implementation of PLM in the design phase of the project enhances the performance, productivity and affordability of the whole project [18]. The main strategic issue for WFS is the management of product design information. Having flexible number of team members for each year requires identifying different structure and role formation. This is necessary as it is difficult to find the same characteristics and abilities for WFS team members of the following years compared to this year. Therefore it is important to have a flexible structure that can be adapted to the changing number of members with varying capabilities in the subsequent years of the project. The main disadvantage of this method can be considered to be the redesigning of the workflows due to having possibly more roles for different purposes. Rigid structure and workflows for the team might not be logical because of limited workflows that might emerge for PDM and a system for dealing with it rather than a coherent system such as PLM.

There is little chance for success in effective use of PLM in FS project since engineers in FS team are changing annually [19] and it is impossible to stick to a standard structure for FS team due to different capabilities and habits in individuals. To understand the relationship between various roles within the WFS team a survey as well as a face to face interview both with the WFS team members and their academic supervisors was carried out. Historic documentations from the previous years were reviewed as an invaluable input. Furthermore an observation by regularly attending WFS workshop was performed to identify the team structure and capture the members' requirements. For similar projects defining the structure and operation in the project and configuring a structured team are considered as the key challenges in the PLM implementation [19]. Complexity of roles and tasks creates a structure that might not be possible to be supported by the conventional PLM system. In this case study the processes should be modified and redefined in order to make them compatible to what is available in the PLM system. This is an essential process for the implementation of the system.

Another solution might be to match the PLM software to the system, which might not be cost effective and is beyond the resources available for the WFS or other similar size projects. This is because PLM software is typically complex and expensive to customise. Tailored PLM solutions can only be affordable by large companies. For example the large number of variability and variances in products from BMW Company caused them to make their own solution based on PDM/PLM concept [20]. However, this approach cannot be pursued by many companies and it is sometimes better to redesign the product processes rather than customising the PLM system itself. This issue can make the implementation of the PLM system into specific projects very demanding.

3.4 Benefits of PLM Solution for FS Project

There are a number of potential benefits in PLM solution implementation for FS project. These benefits can be very broad and in some ways difficult to measure [19]. From the project management point of view the lack of domain knowledge especially for undergraduate students might create an obstacle in achieving success in the project. It should be acknowledged however that many PLM implementation projects fail in their practical phase.

PLM system is very useful in terms of data reuse through creating links between information entities and also linking the related documents to CAD files. In FS project students are mostly working together and therefore there is always a possible risk of data loss when students are collaborating on project face to face or even through emails. Another advantage of PLM application for FS team is clearer border in defining, clarifying and understanding of tasks. During the lifecycle of FS project the high complexity of tasks makes many activities to have overlaps, many of which do not have a defined actor. PLM systems can help notifying and assigning specific tasks to certain roles. In this approach tracking project activities and actors is not a difficult process.

WFS team has always been suffering from time management. Delay from suppliers as well as team members in finishing their tasks are considered as the two main contributing factors to often extensive delays in project stages. Clear visibility of project phases and milestones from the beginning of the project is a critical requirement for the success of the project. This highlights the lack of a systematic approach in data flow from the team to the staff.

Regarding data management each project member should have his/her own folders. Based on the role and defined tasks each member in the team can manage and organise his/her own tasks and associated files and save them based on the defined hierarchies or priorities simply by copying and pasting them in his/her folder. In a sophisticated PLM system, the modification of tasks and roles by members who create their own folders should not affect the overall hierarchy of tasks in the main database [21]. Some PLM solutions can support viewing the CAD files into JT-format or native CAD format which reduces the size of the CAD files dramatically and helps to upload files much quicker [19]. JT-formats are used in visualization, collaboration and data sharing across the product lifecycle [22]. JT-formats assist the process of design especially in collaborative engineering environment. This format is certainly useful in FS project because they are independent from CAD systems [19] and downloadable in less time in comparison with the original CAD files. JT-formats helps to transfer CAD files in better ways to laptops that is more suitable for FS team members who tend to work off campus.

PLM solution helps FS to capture the information needed to fulfil the tasks in a convenient way if they use the system regularly. Methods for retrieving correct information from historical data and data reuse in FS project should be learned by students in order to ensure that PLM will be used in the future. PLM system allows changing implicit information to explicit manners that are required for different stages of FS project. It also decreases the lead time of the project significantly and gives an opportunity to FS team to test and validate the car design first in the simulation world than in the real competition. The latter issue was the main reason for poor result of the WFS in the recent years. Extensive use of the PLM system should eliminate these problems, resulting in constant improvement and higher position for the team.

3.5 Case Study of a Typical Product in the FS Project

"Crash Structure" is a key part of the racing car that needs to be manufactured for WFS project. This component is a deformable, energy absorbing structure situated forward of the front bulkhead in order to absorb the energy of an impact and increase the car safely, ensuring the safety of the driver. Rules and regulations of the competition define certain dimensions for "Crash Structure" and emphasise that the component should be attached directly to the front bulkhead of the chassis [17].

3.5.1 Design

The regulations for "Crash Structure" remained unchanged for 2008/09 compared with the previous year. However, the modifications in chassis had an impact on the "Crash Structure" as according to the new rule the structure needed to be designed in such a way that it fits with cross-sectional part of the chassis. Therefore, several analyses should be done in order to ensure that the "Crash Structure" complies with the regulations. At the beginning it was decided to reuse the last year's "Crash Structure" instead of redesigning a new part. This decision was for time and money saving on design, analysis and manufacture of this component.

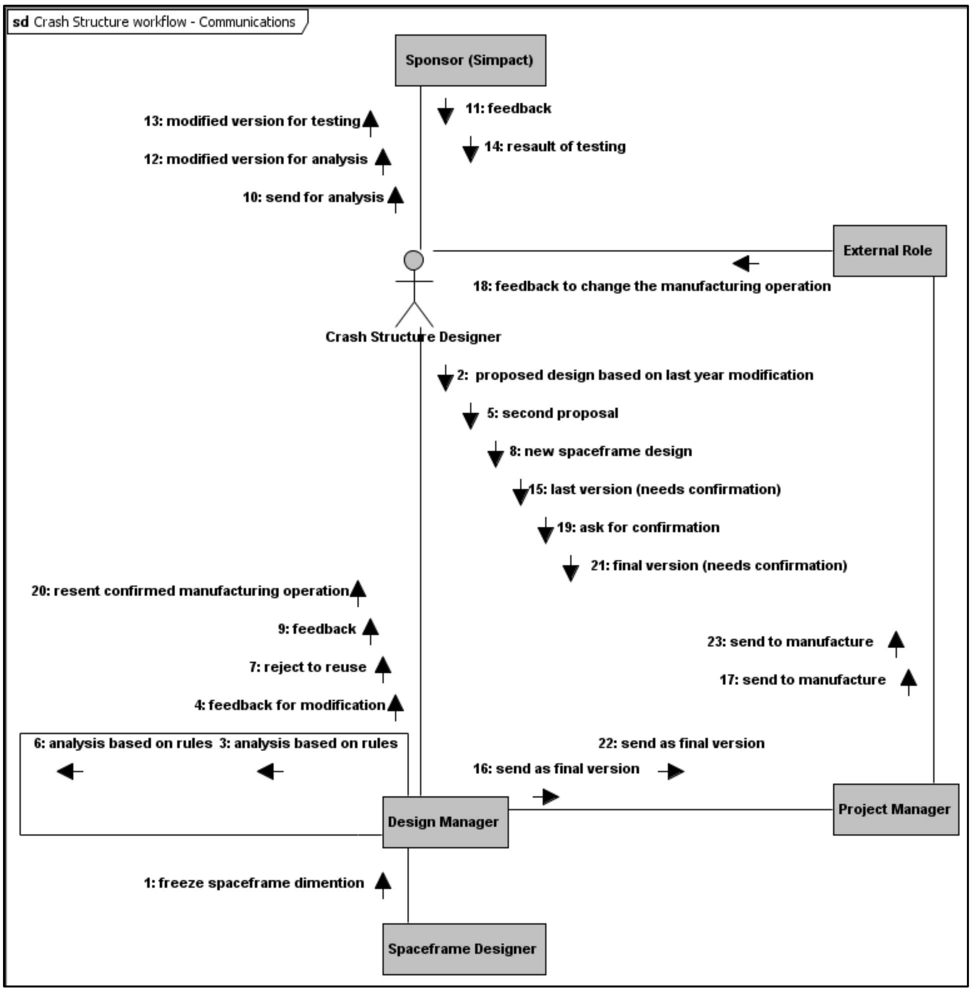

Figure 4 Information workflow for "Crash Structure"

The person responsible for "Crash Structure" proposed to use the previous year's design considering the necessary dimensional modifications essential for fitting the part to the cross-functional chassis. Although this idea seemed to be suitable in terms of dimensions for the project it failed to fit the purpose after analysing and negotiating with CAD manager. This was because the CAD manager was unable to pass the design due to its conflict with the regulations. Therefore in conjunction and with help and advice from the supplier, a new part was designed, validated and tested in the simulation software. The collaboration process with supplier allowed design improvement by a number of iteration based on the test results on material and design. The result was then sent to the sponsor who is specialised in CAM to validate the design and provide feedbacks to the designer. During "Crash Structure" validation and analysis a number of modifications to the product design were performed, which were passed to the supplier via personal visits by one of the team members. This produced a rather slow pace product development process generating further delays.

The communication diagram (Figure 4) shows the current state of information flow between different members involved in the "Crash Structure" design. As can be seen in the diagram, there are several reworks and repetitive loops in the information flow. Early involvement in design and development is considered as the main factors in decision making from the beginning of the processes that can help finding the information for choosing the appropriate strategy for specific processes [23]. In this case study effective early stage collaboration between "Space Frame" designer and "Crash Structure" designer has proven to be a good solution in deciding not to manufacture a new "Crash Structure" and reuse the finished product from the year before. This issue highlights the importance of having a central and effective data management tool that can show all information in detail to individuals engaged in the project.

3.5.2 Manufacture

The lack of data management and clear instructions for cutting the parts resulted in some of the parts to be manufactured twice. This confusion arose from miss-understanding the exact dimensions of the part resulting in resource waste in the form of rework. As can be seen in Figure 5 there were a lot of time spend in stage A. This highlights a poor collaboration between team members. Later in stage B it was decided to design, test and validate the whole part using DM tools. After validating the design conformity in stage B, the parts are then made in stage C. There was a minor change in cross section size compared to the last year's component. The above problem of "Crash Structure" was evident in many other components of the project. The frozen designs of many components were repeatedly changing up to the very late stages of the main product, WFS car assembly.

The final "Crash Structure" manufactured is shown in Figure 6 in the chassis assembly. The fire-fighting style of work did not allow time for a systematic approach for design validation, as the focus of attention was on fitting the parts to their desired position and failing to see the bigger image. It is not surprising for the team to place itself in the 50th place and leave the competition unfinished.

Similar problems can repeat in the consequent years should the lessons learned in this project not be captured, organised and stored. It is crucial for the product information, design processes, product revisions and change processes to be structured and organised for continues development of the WFS car using the PLM system.

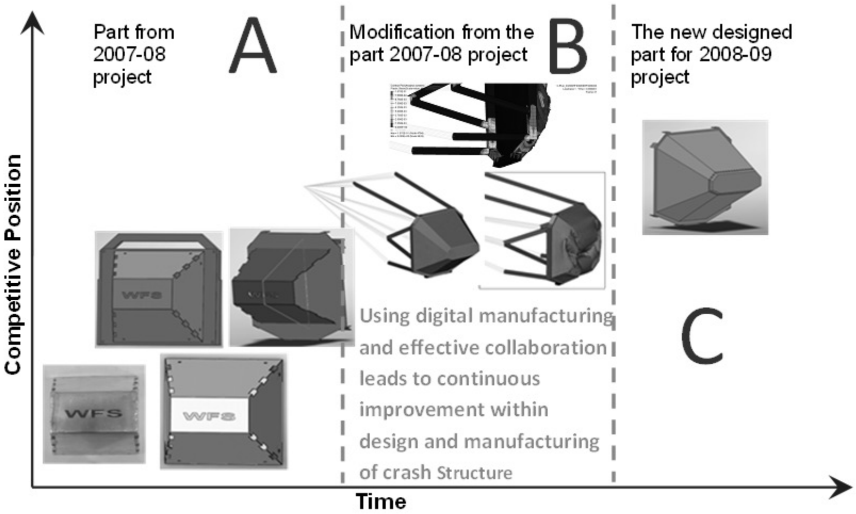

Figure 5 The need for continuous improvement

The above approach guarantees knowledge accumulation that is build on the expertise and practical experience of all the members of the WFS teams for as long as they attend the competition. The current state of work that is a single and all experiencing, learning from own mistake team requires a complete shake up in terms of product lifecycle management. This project as a start up for the full implementation of the PLM system for WFS team has already seen by team members as an approach that can resolve, if not all, many of their existing problems.

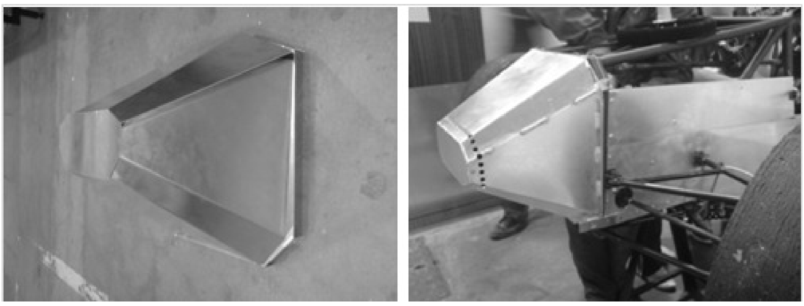

Figure 6 Final crush structure manufactured for WFS 2008-09 entry

4 Conclusion

PLM is the process of the management of product and process related data in its entire life. The PLM concept presents a single central system that can store different types of information. Many companies have already started benefiting from such systems. However, it can be difficult for SMEs to undertake and benefit from PLM system from the start. Lack of domain knowledge from SMEs in terms of the importance of document management and data classification is considered as a barrier towards PLM implementation. In addition there is a reliance issues making SMEs reluctant in working with such tools.

In this paper to provide an example of PLM implementation a case study is used that is the Formula Student project at the University of Warwick (WFS). The project team has constantly suffered from weak performance particularly in the design and manufacturing phases of the project. The same scenario happens each year due to poor collaboration among team members. This is regarded as a classical problem in many SMEs.

WFS project requirements can be supported through the use of a major PLM system. Using PLM allows the team members to understand their tasks in detail. PLM system in design phase helps the team to have all the historical information about the suppliers and the issues that happen to a particular process in the previous projects. The research nature of WFS project makes it a suitable case study for PLM implementation as it contains a degree of flexibility for examining different alternatives for implementation. A typical product of WFS project was chosen as an example to show the behaviours of different elements such as team members and suppliers, competition rules in the project. This example highlighted the problems in the WFS project in terms of communication, data management, workflows and data storage. This flexibility that is mostly created from the team itself allows processes to fit the project with PLM system specifications. It also counts as a good experience for WFS project members to become familiar with complexities and challenges of data management in the real world.

This case study showed and emphasised the importance of data management to the extent that it can be viewed as a key competitive advantage for WFS team. The team ranking prior to the PLM implementation time (2009) was 50 in the UK. After managing the project data the team achieved and overall ranking of 7th position in the UK and 22nd worldwide [17]. It is fair to think that a considerable amount of this improvement is due to the above PLM system implementation.

Finlay it can be recommended for formula student organisers to include data management method as one of the competition topics in addition to the conventional areas such as technical inspection criteria, design, cost, durability, etc. This study showed that a solid and reliable data management system can bring many competitive advantages leading to an increased rate of success.

Acknowledgment

The authors wish to thank Warwick University Formula Student Team of 2008/09 and their supervisors Dr Steven Maggs and Dr Neil Davis for their valuable inputs.

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Chapter 6
Product Lifecycle

Robotic disassembly of the waste of electrical and electronic equipment (WEEE), based on the criteria of identification and analysis of waste characteristics, presented on the example of computer hard disk drives

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Abstract: The article examines the solution of a simplified robotic dismantling of electrical waste and electronic equipment (WEEE), as means of materials recovery. The paper provides criteria for selection, identification and waste analysis, enabling significant simplification of applied solutions in robotic dismantling workstations. Based on proposed criteria, the waste of computer hard disk drives (HDD) was identified, analyzed, and their characteristics described. Furthermore applying described simplified approach to robotized disassembly, the complete process of dismantling of HDD covering all the procedural steps was presented for the selected disk. Described simplified disassembly process can be performed with use of 2 robots equipped with, 2 tools and one conveyor handle. Author also briefly presents issues related to proposed simplified process approached during HDD waste disassembly studies. In addition, paper presents the quantities of materials to be recovered from the HDD waste.

Keyword : WEEE, robotic, disassembly, waste, identification, criteria, recycling, recovery of resources, HDD

1 Preface

Waste of electrical and electronic equipment [WEEE] is a global concern. In the 27 EU countries it is estimated that the weight of produced waste WEEE in 2005 was 8.3-9.1 million Mg [tones], 25% of which is collected and processed, while remaining 75% is not registered and does not occur in collection points[1],[2]. Such state of waste management system can be caused by lack of processing capacities and suitable technologies which can utilize WEEE effectively. The amount of WEEE rises continuously[3],[4], in 2008 Sweden collects 16.7 kg/capita of WEEE, Britain 8.2 kg/capita, Austria 6,5 kg/capita[5]. Moreover European Commission proposes rising collection targets from 4kg/capita to 65%[6] of average mass of electrical and electronic equipment placed on market. WEEE has to be utilized, but it also can become a source of valuable resources.

The factors described above reveal the need for development of new ways to process WEEE effectively allowing recovery of valuable raw materials. It is believed that robotized disassembly can be the technology that will take a part in solving WEEE processing problem.

2 Currently used technologies for processing WEEE waste

There are two main waste treatment methods of WEEE: manual dismantling, and mechanical methods based on shredding, and multistage separation of materials. Manual dismantling and mechanical processing approaches differs between each other, on the degree of recovery of raw materials from WEEE waste. Recovery ratios are presented in table 1.

Table 1 Recycling methods recovery ratio[7]

	Washing Machine	Oven
Shredding	44,1%	74,9%
Manual system	95,6%	90,6%

Manual dismantling is the most flexible way to process wide range of different electrical and electronic equipment waste, and have the highest recovery rate of raw materials. However, manual dismantling is very extensive and requires direct human contact with waste. Manual dismantling is based on removing the components from the devices, and theirs segregation accordingly to the materials they are made of. Often manual removal is the first stage in the process of mechanized waste treatment technology (shredding), to extract the hazardous substances and components which cannot be processed together.

Mechanical treatment of waste, is based on shredding process, after which, shredded residue is separated in multistage process to obtain rich fractions of resources. This method is useful to process large quantities of mixed WEEE waste, but its disadvantages are, high energy demand, associated with the shredding of waste, lower level of resources recovery, and impurity of recovered raw materials.

Nowadays, works are being carried out to **robotize WEEE waste processing methods**, as an alternative to existing processes, and as supporting solutions for others existing ones. The example of such works is modeling of the dismantling line to utilize LCD monitors[8]. Another type of work being carried out, is to robotize dismantling process of desktop computers[9]. In literature are also presented works covering prototype automation solutions replacing certain activities in existing WEEE processing plants i.e. Automatic unscrewing of extracted washing machines engines, transporting released parts using robotic arms equipped with grippers, etc[10].

Robotized dismantling is the alternative to traditional technologies, (shredding and manual processing). It combines the advantages of traditional technologies, theirs capability to adapt to various wastes, with large processing capacity. Robotized dismantling allows to obtain high purity of raw materials recovered from waste, with minimal energy input and no human labor (no human contact with waste).

3 Overview of robotized dismantling technology

Robotics applications in waste dismantling are based on well known and applied in modern industry robotics and automation solutions. Robotized dismantling can be described, as reversed process of robotized manufacturing, or as replacing human labor by robot in repeatable operations during dismantling process. Knowing the dismantling steps, actions and procedures performed during manual WEEE processing, it is possible to replace them by robotized tools. Complete process can be organized in form of demanufacturing line, equipped with robotized tools, on which, step by step performed are successive actions of dismantling process and resources are being recovered.

Due to the speed of robots, repeatability and positioning precision, it is possible that robotized disassembly unit will be small, and it will process large quantities of waste.

The main advantage of robotized disassembly is its **energy efficient method** used to separate screwed together components. Energy efficiency is obtained by: applying automated screwdrivers controlled by robot arm to free screwed together parts, and robot arm grippers to remove freed parts, and carry them to right container. Unscrewing and carrying operation, are the least energy consuming actions, so they offer great energy savings in WEEE processing, combined with obtaining the highest possible purity of recovered resources. Such approach differs from shredding method, that consumes huge amounts of energy, required for cutting metals and plastics into pieces.

Unfortunately due to extreme variety of WEEE **not every waste can be processed in robotic disassembly unit**. That is why it is fundamental to arrange ways allowing to categorize which of WEEE can be processed in this particular way. Moreover there are two approaches to robotic disassembly of WEEE, that differ due to the level of theirs complexity.

4 Complexity issue in robotized disassembly – opposite approaches

The robotized disassembly can be performed in two ways: fully programmed, **linear algorithm** of operations, and on the other end, **dynamic algorithms**, organizing the operations accordingly to the data collected from sensors.

Applications of **dynamic algorithms**, self adapting to the data collected from sensors, is very complex and multidimensional. Self adapting approach requires advanced sensors, operations on collected data and analysis of possible operations to be performed, this makes it difficult and expensive. Due to such high application requirements, dynamic approach is not analyzed in this paper. However in future it is possible that this complex approach may occur effective in mixed waste processing, or as an part of other systems.

On the other hand robotized disassembly can be based on **linear algorithms,** allowing effective and simple application of this technology in WEEE processing plants. Each step, in the disassembly process, is strictly programmed and is performed in its time, embedded in the chain of disassembly program. Whole program is linear and fully determinated. However this approach can be only applied to uniform wastes, where once programmed operations can be performed on large volume of devices, leading to the same constant and predictable effect.

Linear algorithms simplify the complexity of robotic solutions, decreasing the necessary data collection to minimum. Disassembly algorithm is in form of basic preprogrammed, repeatable operations, in a result of which appliance disassembly is performed. Once programmed disassembly unit, will carry out the program on any number of identical devices.

However due to wide variety of WEEE, even in categories of waste i.e. IT equipment - laptops, routers, differ between models and versions, so it is necessary to equip disassembly unit in optical recognition system (bar code reader, or camera) to identify its brand, model, version to choose the right program for identified device.

The drawback of simplicity of robotic disassembly based on linear algorithms, is that the disassembly unit is designed for specific waste (certain tools are used), so only similar wastes can be processed. That is why, it is not possible to process i.e. LCD, laptops and ovens on one robotic disassembly unit. However, it is possible to process i.e. all models of all manufactures, of hard disk drives.

Identified specificity, of the simplified robotic disassembly approach, based on linear algorithms, requires methods to select and analyze, which of the range of WEEE can qualify, and is reasonable to process in this technology.

5 Criteria for identification and selection of waste qualifying for robotized disassembly, based on linear algorithms

Not every waste can be processed in robotic disassembly unit, due to its characteristics and other factors that limit applications of this method.

To identify WEEE qualifying for being processed in simplified robotic disassembly technology, certain **criteria were developed and verified**. The criteria are:

- **Physical characteristic**: similar construction, standardized external dimensions, standardized placement of mounting holes, construction easy to dismantle, small amount of homogenous parts, good physical shape, no deformations, no dirt, way of identification i.e. by barcode.

- **Market factors**: life cycle of the product on the market, quantity and mass on the market, upward trend in sells.

- **Resources to be recovered**: amount of valuable/dangerous resources, which recovery is economically reasonable/necessary (law).

- **Environmental impact**: decrease of amount of waste, recovery of the resources decreases use of natural resources.

- **Additional criteria**: the ease of extraction of identified item from collected WEEE, currently ineffective recycling methods i.e. high energy consumption, low recovery rate, contamination of recover resources.

Applying above criteria to WEEE, several types of wastes have been identified and qualified for robotic disassembly method of recycling. Detailed analysis was carried out on computer hard disk

drive, which was chosen, as a **waste appliance that meets all above criteria**. (Figure. 1)

Figure 1 Example of computer Hard Disk Drive (HDD) 3,5” view from electronics side

6 Characteristics of hard drives as a waste eligible for processing in the simplified robotized disassembly technology

Hard disk drives can be found in computers and other devices, like IT or broadcasting equipment, often HDD’s are found alone in waste, due to rapid obsolescence of IT solutions. Given the number of hard drives sold worldwide in 2009 [550 million units], estimated mass of waste of HDD every year is 280 000 Mg[11]. The mass of HDD waste is arising annually, and is significant enough to justify materials recovery from it and search for the new technology to process this appliance waste alone.

Computer hard drive has standardized external dimensions [few models such as 2.5 ", 3.5"]. The design is simple and based on uniform chassis in which components are installed. Extraction of the hard drives from computers is a standard procedure in many companies that process WEEE. Their physical condition is good - without deformation. Also important parameter is what kind of materials can be recovered from HDD waste. In the case of hard drives mainly they are: aluminum, ferromagnetic metals (and magnets), stainless metals and other mixed scrap (table 2).

In addition, literature shows that, research is performed to robotize dismantling of computer[12] components. This will allow in future for integration of robotized computers disassembly, with robotized dismantling of every component, directly to recover raw materials in one process.

Table 2 Average mass and groups of resources in hard disk drives 3,5”[11]

Type of material	Average mass of material in 3,5” HDD	
	Mass [g]	Content % in HDD mass
Overall HDD	515	100,0
Aluminum	264	51,3
Ferromagnetic metals	90	17,5
Stainless metals	53	10,3
External electronics	41	7,9
Other components	66	12,8

7 Complete and partial disassembly of WEEE

Performed research showed[11] that the dismantling of waste, can be performed in two ways, full and partial disassembly of appliance. The level of dismantling depends on quantity and purity of recovered raw materials, and on the other hand is limited by its difficulty.

In some cases the complexity of disassembly of appliance will be too high for its complete robotic processing, and only partial dismantling will take place i.e. to remove dangerous substances, covers, and other easy to remove parts, as the pre-treatment method. Some of the raw materials will be recovered, overall mass decreased, labor saved, and energy demand for further processing decreased.

Both variants, full, and partial disassembly, are described on example of computer hard drives:

Partial dismantling – is the removal of the external screws and external electronics, as well as the closure of the disk, followed by several internal bolts. It is possible to carry it out using two tools – a screwdriver, and a gripper. As a result of the partial dismantling, 8% weight reduction was achieved. [removed were: bolts, electronics, closure of the disk]. In addition, the source of heavy metals and organic matter – (electronics) is removed. This situation presents figure 4.

Full dismantling - is the removal of every component from the HDD chassis. This procedure allows to reduce the mass of waste HDD by 87% and recover pure resources like aluminum, stainless, and ferromagnetic metals. The rest, 13% or the input mass is not processed, this "other" components group contains: plastic (2%), disk heads (3%), motor (8%). All components extracted from disk are shown on the figure 2.

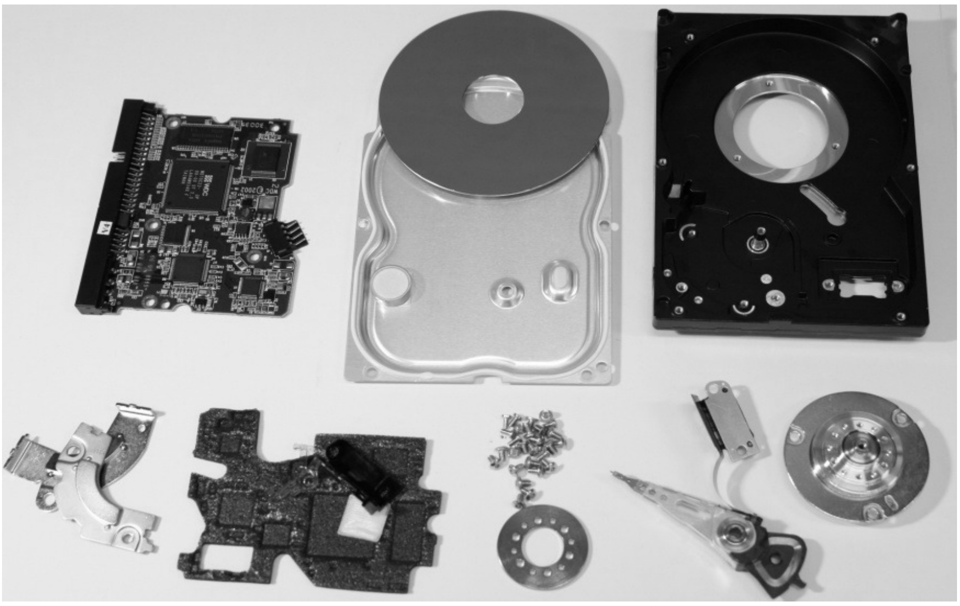


Figure 2 Fully disassembled hard disk drive

8 Robotized hard disk drive dismantling line - process implementation based on simplifying linear algorithm

Robotized process organization example, is presented on Western Digital Caviar WD400JB-00ENA0, hard disk drive manufactured in 2003 with a capacity of 40 GB. The block diagram of the proces is showed on table 3.

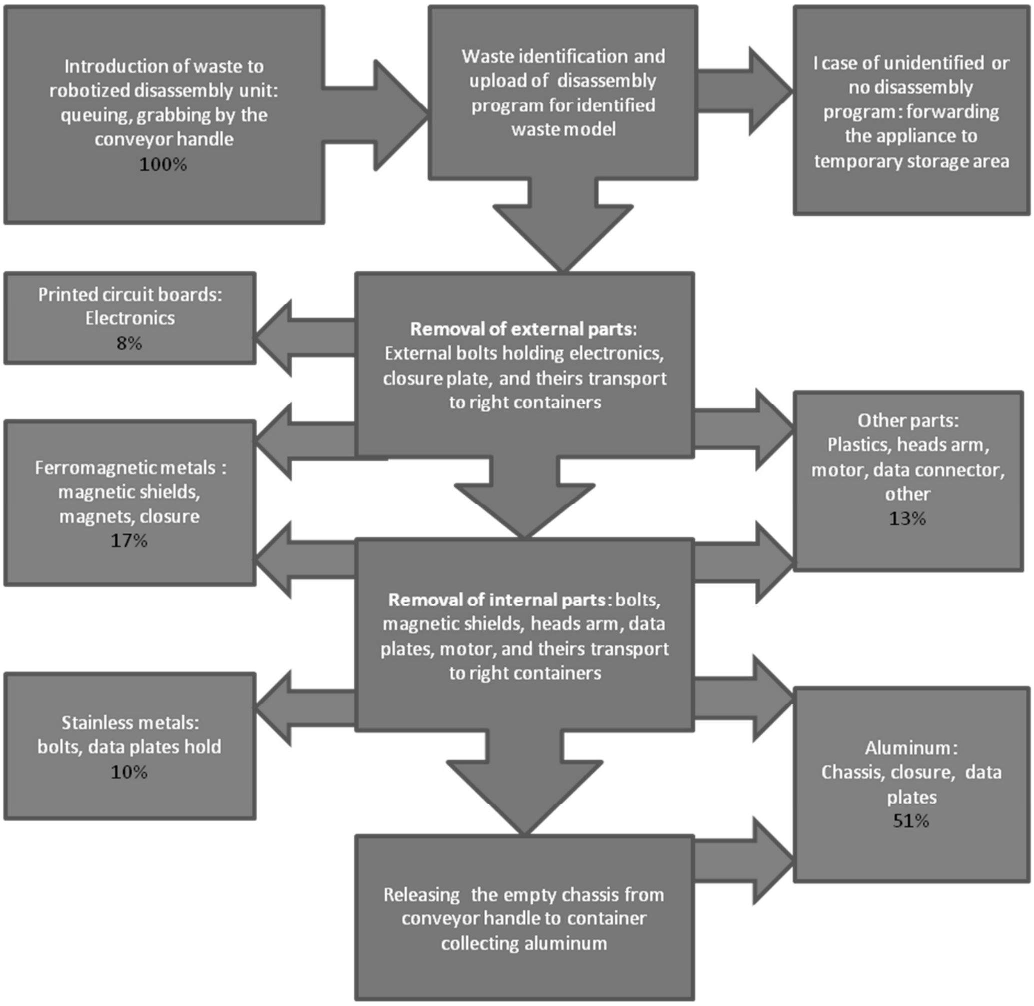
Hard drives, extracted from computers, are introduced into the disassembly line directly on the conveyor belt. HDD's are being queued and positioned on it, to allow each disk to be grabbed by the handle, enabling the spatial manipulation. Construction of hard drives is based on the aluminum chassis fitted with standardized threaded holes for mounting the drives. In the case of the disassembly those holes can be used to hold the disks in the handle and manipulate them. Placement of the holes in the chassis is shown on the figure 3.

Next step is identification of the hard drive. Model of the HDD is identified by reading barcode or other OCR method. On this basis program is selected and uploaded. In the case of absence of the program for a given drive, or the inability to read the model, the disk is forwarded to the interim storage.

Immobilized in the handle hard disk is transported to the robots operation area, where the first stage of dismantling is being performed. Threaded joints are disconnected by first robot equipped with automatic screwdriver. This operation frees electronics. Second robot equipped with gripper removes electronic board from the drive and moves into the container collecting electronic parts. Next, the drive is turned 180 degrees around in the holder and in the same manner, the removal of the top plate is executed. Threaded connections of the cover to the chassis are disconnected and the cover is transferred to the container collecting aluminum. Exposed components after disassembly of cover plate are shown on figure 4.

Figure 3 Placement of mounting holes in chassis of disk – pointing by arrows

Table 3 Block diagram of disassembly process, with percentage of raw materials in HDD’s



Following, joints are unscrewed inside the disk, holding magnetic shields with magnets on them (Figure 5), than plates on the rotor, data connector and finally heads arm. In the case of plates mounted on the impeller it is necessary to immobilize the motor so the screws can be localized and unscrewed. This operation can be implemented using the gripper from the second robot arm. However, pinpointing the exact location of the bolts is only possible via optical system or proximity sensors in which the disassembly unit have to be equipped. Another element to disassemble is the disk head, this part is mounted using other type of screw connection, therefore it is necessary to replace the tip of the screwdriver on robot arm to perform this operation. The last operation is to dismantle the motor.

Figure 4 Exposed components after disassembly of cover plate

Figure 5 HDD during components disassembly – arrows pointing glued magnets

During each unscrewing operation, second robot equipped with gripper, simultaneously picks and moves released components to right container, collecting each raw material. After disassembly of all components from the disk, its empty chassis made of aluminum, is released from the handle above the container collecting aluminum components. This operation finishes the process of dismantling of the hard disk. All dismantled components from hard disk drive are presented on figure 2.

Table 3 presents block diagram of the process described above, together with the participation of recovered materials.

Described investigation of disassembly process of HDD, covers all identified standard procedures and proposes solutions for process design. However, not all computer hard drives are made in the same way, some components are assembled by negative allowance or glued together, also some drives are sealed by aluminum seal tape etc., those non-standard construction solutions used in hard disk drives, complicate and require introduction of additional tools to disassembly process. In the case of uncommon, complex and uneconomical to process lots of drives it is possible to carry out a partial disassembly of them, and forward them to another process that can handle the rest of the process i.e. manual dismantling.

Currently manufactures of many appliances are foreseeing the utilization issue, at the end of life of theirs products, and the products are design much simpler than it was in the past. This approach brings savings during production, and utilization. The general trend is, the newer the appliance the less complicated its construction and more uniform each type of waste collected.

9 Summary

Presented in the article approach of identification of waste eligible for processing in technology of simplified robotized dismantling by linear algorithms, allows finding application of this technology, to provide significant reduction of cost in waste processing.

Based on presented case of HDD disassembly activities, whole process can be designed and calculated for research trails and testing purposes. HDD case shows that it is possible to implement whole disassembly process using: conveyor handle, and two tools mounted on two robotic arms.

Robotized WEEE dismantling technology is new and effective way to process this group of waste. Its high efficiency and speed, allows to process large volumes of selected groups of wastes, recovery of valuable and high purity resources, and to avoid human contact with waste.

Estimated on example of robotic disassembly of hard disks, based on the volume of the world production of HDD's [550 million units = mass of 280 000 Mg], it is possible to recover: 143 600 Mg of aluminum, 49 000 Mg ferromagnetic metals, 28 800 Mg stainless metals, 35 800 Mg of mixed metals, and 22 100 Mg of printed circuit boards, each year.

With additional treatment of extracted components, it is possible to recover raw materials like rare-earth metals, and certain quantities of precious and heavy metals embedded in the printed circuits. This allows for almost 100% high level of recovery in the case of presented hard disk drives.

The author believes that the use of simplified robotized technology, on industrial scale is reasonable. It is believed that robotized disassembly is also the future of the waste processing industry, and an unique opportunity for companies offering robotic solutions to arise on the markets of WEEE processing.

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Using the Extended Product Concept to better Understand New Business Models along Product Life Cycles: The Case of E-Mobility

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Abstract: Concepts like extended products and product-service systems have been discussed for years. So far several publications have highlighted the relevance and showed examples. While taking services into consideration the focus is shifting from the realization phase of a product to its life-cycle. The changes of customer behavior as well as the trend towards new mobility paradigms are challenging manufacturers and service providers to come up with new solutions and new business models which better reflect the needs of the customer and the society. We believe that E-Mobility provides an ideal case to investigate how tangible and non-tangible products and services can be integrated using the extended product concept. In this paper the extended product concept will be analyzed and applied in the domain of E-mobility in order to better understand the development of business models along Product Life Cycles.

Keywords: E-Mobility; Extended Product, Business Model, Product Life-Cycle

1 Introduction

Electric mobility (E-mobility) is one of the big trends in the automotive field these days. For a more sustainable mobility electric powered individual transportation is a current subject for several players not only for automotive but also for energy and infrastructure providers. The German National Development Plan for E-Mobility aims on pushing research and development, market preparation and market launch for electric mobility. It stipulates to have one million electric vehicles on German streets until 2020 (Die Bundesregierung 2009). The focus of research is on the one hand by technical nature in means of developing new electric powered cars and infrastructure solutions. On the other hand the research is focused on developing and implementing new mobility services which are valuable mobility solutions for the customers. Developing new products and implementing new services based on these products is highly interdependent. To successfully provide a new mobility service a high degree of collaboration between the different market actors is necessary.

For a successful implementation of new and innovative products and services it is feasible to generate extended product concepts. We think that e-Mobility provides a playground to investigate how tangible products and intangible services can be interpreted using the extended product concept. With the extended product concept the two big constraints in the field of e-mobility like limited range and high price might be countervailed. We also want to map an extended product life-cycle on e-mobility. At the end we want to illustrate an exemplary usage of the extended product concept in order to state the linkages between the different actors providing several aspects of e-mobility.

In this paper the extended product concept will be analyzed and applied in the domain of E-mobility in order to better understand the development of business models along Product Life Cycles. It will be illustrated that E-mobility itself is a complex subject and that there is a need for the integration of various products and services. Consequently section 2 of the paper discusses approaches and challenges. Section 3 provides a short overview of the extended product concept used in the paper. This is followed by section 4 discussing e-mobility, a lifecycle concept and an exemplary usage in the context of e-mobility. Some conclusions finalize the paper.

2 E-Mobility: approaches and challenges

At this time almost every automotive OEM is investing significantly into developing electric vehicles and soon first models will be released to the market respectively are already available now. Numerous studies from investment banks, consulting agencies and research institutes tried to predict how the electric automotive market will develop the next ten years. Predictions differ in a wide range from 2 to 25 % (!) market penetrations in 2020. In automotive terms this is only one and a half model cycles from now (Arthur D. Little 2010).

2.1 Challenges in e-mobility

Electric vehicles not only have the big advantage of zero local emissions (zero emissions when using renewable energy sources); their power efficiency is higher, the components don't need as much maintenance, environmental noise is lower and driving characteristics are better than conventional power train cars. But even though the advantages are clear and the first electric vehicles are released on the market now E-Mobility still has three major problems to face:

- Electric vehicles are expensive.
- The range of electric vehicles is quite limited.
- There is not yet an infrastructure implemented to "refuel" the vehicle like we are used to it today.

2.2 From selling to providing

The automotive industry is facing another challenge: the future customers not necessarily need to own a car. More than 80 percent of the 18 to 29 year old think that city inhabitants don't need to own a car (Spiegel Online 2011). The urbanite of tomorrow is looking for more flexible models like leasing or car-sharing to satisfy his individual mobility demands. In future markets more and more players like OEMs, leasing or service companies will be involved and fight for the mobility budget of the customers. Consultants from Arthur D. Little identified three so-called “mega trends” (global factors which set up the framework for all areas of business and society for 30 to 50 years), which will play a role in shifting business models and the uprising of electrified vehicles.

- *Neo-ecology*: Initially arisen from the environmental movement of the 80’s, society expects a corporate social responsibility. The rise of the oil-price and the CO2-discussion accelerated this mega trend enormously, and products which are not developed considering this trend are almost not marketable nowadays.
- *Individualization*: This mega-trend describes the release of the consumer from mass movements towards individualized solutions. Traditional lifestyle models are being left throughout all social classes and customers enjoy being not conformed but individuals.
- *Mobility*: In the 60’s and 70’s there has been a significant quantitative rise of mobility in triad markets and BRIC markets followed with a little delay. Limitations or harmful impacts of mobility for example traffic volume and CO_2 emissions though were reflected in society much later.

Along with the mega trends social and consumer trends which affect demand and buying behavior of consumers with a time horizon of five to ten years have been identified as well. Trends as Downaging, New Luxury, Cheap Chic, Simplify, Deep Support, Family 2.0, Multi-Graphy, Neo-Cities and Greenomics will have an impact on the demand for mobility especially in triad markets (Arthur D. Little 2010).

These trends are leading not only towards an evolution of automobiles from conventional combustion engines towards electrified vehicles, but they will also lead to new business models respectively to an extension with intangible product related services.

Today’s automotive market is slowly drifting from the conventional model, where a car is bought and owned by the user towards models where cars are rented, shared or leased. The customer has a requirement for mobility but that doesn’t necessary mean that there is a demand for owning an automobile. Requirements describe the customer’s needs, while the demand describes a specific item that satisfies these needs. Walking along with the extended product paradigm, which will be shortly introduced in the second part, the focus of manufacturers and suppliers is moving from producing and simply selling tangible core products to providing solutions which satisfy the customer’s needs.

Within this paper we are introducing an approach to model future business models over the product life cycle of e-mobility by combining a lifecycle model with the concept of extended products presented next.

3 The Extended Product Concept

The change in customer demands is reflected by the Extended Product (EP) concept [Thoben, et al. 2001, p.429]. An EP is an integrated offer of a physical product “extended” by services aiming at the provision of a customer oriented solution. While taking services into consideration the focus is shifting from the realization phase (Beginning of Life (BoL) of a product to the usage phase (Mid of Life (MoL)) as well as the recycling phase (End of Life). Baseline for the development of the EP concept was the need for a better understanding of the development of new IT-based business model supporting the entire life cycle (LC) of a product.

The EP concept can be illustrated in a model consisting of three layers, the kernel as a representation of the core functionalities of a product (core product or product in a narrow sense), the middle layer representing the overall product (packaging) and the outer shell describing the intangible parts of the offer (services) [Thoben, et al. 2001, p.435].

At the same time customer demands change, the focus of value generation moves from production towards the pre- and post-production phases in product development [Eschenbächer, et al. 2002, p.677]. For the conception and development of EP the complexity rises in the fields of product functionalities, production resources and the incorporation of the whole product life cycle (PLC). Taking into account the overall PLC of products the requirements for and definition of products change.

Being aware that a lot of added value can be generated with product assets, companies are consequently shifting their business focus towards the offering of solutions or even the provision of benefits as illustrated in Figure 1.

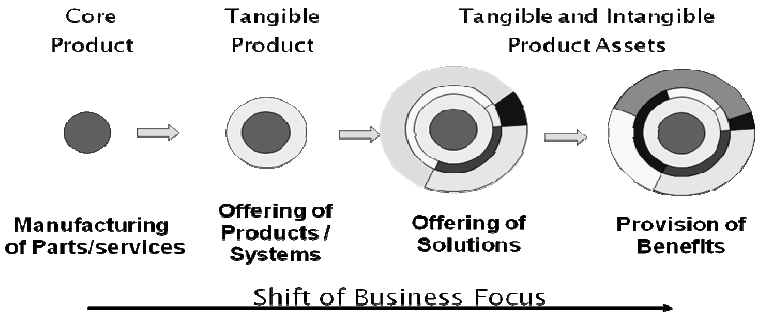

Figure 1: Shift of business focus: From manufacturing of parts to the provision of benefits

With the concept of Extended Products the business models for all stakeholders in e-mobility should be described. The authors do not describe the e-vehicle as an extended product, but a network of Extended Products from multiple stakeholders as a concept to offer e-mobility. In the following we will discuss the extended product life-cycle in the context of e-mobility.

4 E-Mobility in a Product Life Cycle Model

4.1 Interpreting E-Mobility in a business model related lifecycle

As described in the previous chapter the market for "mobility service solutions" is expected to change in the next years. Especially in big cities customers will demand mobility without owning a car. E-mobility services can be seen as a solution for the new requirements but several problems are not solved yet. “E-mobility service solutions” will be operated by several stakeholders like automotive OEM, infrastructure providers, mobility providers or electricity companies. All of them will play a role within the transformation from fuel powered cars towards electric cars.

The aim of the approach presented below is to visualize the complexity of e-mobility to structure a value chain for multiple stakeholders over the full life cycle. This first iteration of the approach focuses on the automobile as a starting point of view.

4.1.1 The core product: Electric Vehicle

The core of the product is divided in the car components and the battery. It states all elements to fulfill the functionality of the product within the core. Car components in the field of e-mobility like chassis, interior, heating respectively air condition or power electronics will evolve (e.g. through light weight construction or higher grade of efficiency) and will have a high impact on product usage and business models, since the customer is most likely not willing to make any kind of cut backs in terms of comfort and usability of the vehicle.

E-mobility at this time is highly dependent from battery technology, as one could say today the battery might be the technical barrier which has to be breached for the success of electrified vehicles. The batteries available nowadays are heavy, big and expensive. This results in a limited range and limitations in storage volume which are directly dependent from size and capacity of the battery. The more For example a Li-Io battery for an electrified Smart, would need a capacity of 16 kWh for an operating distance of about 130 km. Production costs of this battery is between 7.000 to 8.500 Euros (75% for production costs in small batch series and 25% for raw materials) (Bain&Company 2010). This is almost the same price as for the rest of the car and the operating distance can’t even slightly compete with traditional power trains. With such a high price the battery seems to be not suitable for classical approaches which are based on selling and buying a product.

There are two essential drivers which can push E-mobility, either the cost of oil, gas and CO_2 emissions increase drastically or the cost of the battery decreases to a sellable level. Of course quality levels in cars such as technical interior (navigation, park assistant, etc.) customers know from present standard cars are also important - especially when they are not available at all. It’s obvious that the costs of batteries will drop, when using mass-production and further technology research (see the case of Li-Ion Laptop batteries, where the price decreased about 80% in the last ten years). Calculations predict that the cost of batteries in 2020 will be only 35-40% of the costs from 2009. Another recent study estimated a market volume for the battery of 20-22 billion euro alone in Europe (Bain&Company 2010).

The circle around the core product constitutes the overall product “electric-vehicle”, including the car and the battery. On this level the differentiation from competitors is in focus. Differentiation is taking place within design of the car, technical exterior/interior, brand conformity, etc. Today’s providers of this shell are the automotive OEM. Within these early phases of e-mobility other players are becoming providers of cars as well, especially suppliers of electricity. Mostly these companies provide first fleet tests with modified products from OEM and re-brand these (e.g. RWE).

4.1.2 Extended Product oriented Life Cycle model

The components and the overall product will have a life cycle divided in the Begin, Mid and End of Life. The different phases of the life cycle offer multiple opportunities for extended product concepts to the stakeholders in e-mobility. Mayor players for these new products and services are the car manufacturers (OEMs), battery developers, infrastructure providers, electricity providers and mobility providers. It becomes obvious that these players partly offer competitive but also complementary products. Moreover the life cycle of these offers differ massively from each other. In Figure 2 we converged the shell concept of Extended Products with the three different lifecycle phases of a product.

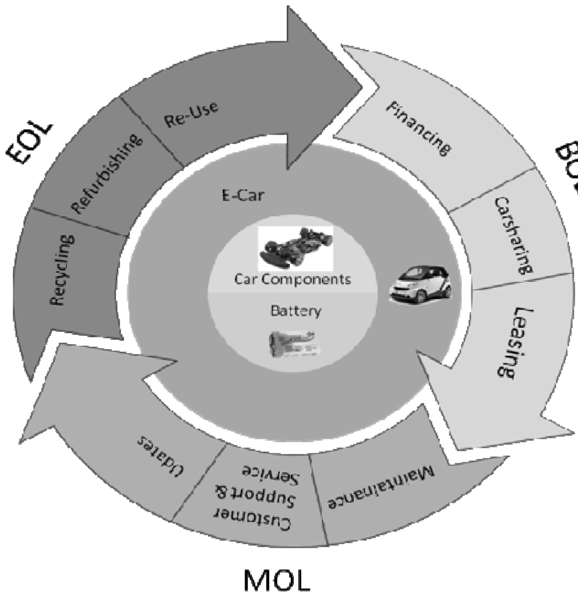

Figure 2: EP oriented product lifecycle

Begin of Life

Business models in the beginning of life phase can be the currently known ones for car manufacturers. It starts within begin of life (BOL) with the vehicle development, engineering and production (Pahl, et al. 2005). To match the future development requirements coming from the market of e-mobility solutions this phase will be constantly evolving as well as shifting from the involvement of OEMs only towards collaborations between the different players in the e-mobility field. The development of charging stations for example needs to be standardized and considered already during the vehicle development. At least players like battery developers and infrastructure providers need to be involved in the vehicle development. As every player wants to get a piece of the cake as big as possible it seems to be logical, that energy providers will not only focus on the revenue of electricity alone, especially due to the fact that the amount of additionally needed electricity for e-mobility will be quite small.

Charging stations with a monthly paid fee could be a solution for this issue, but the authors subsume that this model will not play any important role in the future. Certain extended product concepts presuppose cars which are specially designed for the needs of that specific concepts e.g. the model introduced by “better place” requires vehicles which are designed with a changeable battery, compatible to their battery changing stations infrastructure (Better Place 2011). Many companies who want to become a player in the e-mobility field started strategic alliances with big car OEMs, for example Nissan Renault with the infrastructure provider “Better Place” (Renault 2009). There is a strong interdependency between the battery and the vehicle which necessarily leads to co-creation in the product development phase. Infrastructure providers also need to develop the charging stations in BOL.

Mid of Life including sales, usage

Within Mid of Life (MOL) car manufacturers traditionally offer spare parts and maintenance services as well as customer support and -service (Klimke 2008). In maintenance services replacement and modification of vehicle parts could be established as upgrade services e.g. replacement of engine or battery for higher performance respectively range. As technologies will evolve modernization services might be also feasible for the mid of life phase. If for example the fuel cell technology, reaches its break-through, battery powered vehicles could be equipped with a fuel cell as a so called range extender. Accompanying further services might be offered like e.g. own car sharing models, and fleet management for business customers.

End of Life

As car producers in the European Union have to take their cars back by law various recycling related activities can be seen as a source for new services and related businesses models during the End of Life (EOL) phase. Another service could be the replacement of the vehicles battery, as the batteries life might be shorter than the vehicles life. Old batteries need to be either recycled according to national laws or they could be used subsequently for other purposes, e.g. as Uninterruptible Power Supply (UPS) for Servers.

A niche in the end of life phase could be the refurbishing of used vehicles in a way which makes the vehicle more attractive for new potential buyers’ e.g. equipping the vehicle with a new battery or new upholstery etc. to bring the vehicle in a “as new” condition to sell them.

4.2 *Extended products in the context of -e-mobility -*

Meanwhile, many case studies (e. g. Deloitte 2009) in different branches illustrate the applicability of the concept - especially in the area of e-mobility. In addition to the electric car itself, maintenance processes regarding battery charging, loading infrastructures or energy management must be adapted to the customers.

Figure 3 can be understood as business opportunity matrix reflecting the most important components and the product life-cycle. In this matrix we have positioned the actors and their products. The four elements (stakeholders, product life-cycle, components and extended product concepts) have been brought together to demonstrate the ultimate need for integration in e-mobility. The product life cycle is shown on the top of the diagram. The phases indicate in which phase the various stakeholder can be positioned. Relevant stakeholders are the battery producer, the automotive OEM, power provider, infrastructure provider and mobility service provider.

4.3 Illustrating the complexity of EP concepts for e-mobility

The definition and specification of product and services for e-mobility is complex. Many different organizations need to combine resources and competencies to finally enable new Extended Product concepts (Thoben et al 2002). In the following, we will provide an explanatory example demonstrating how potential collaboration requirements can be identified.

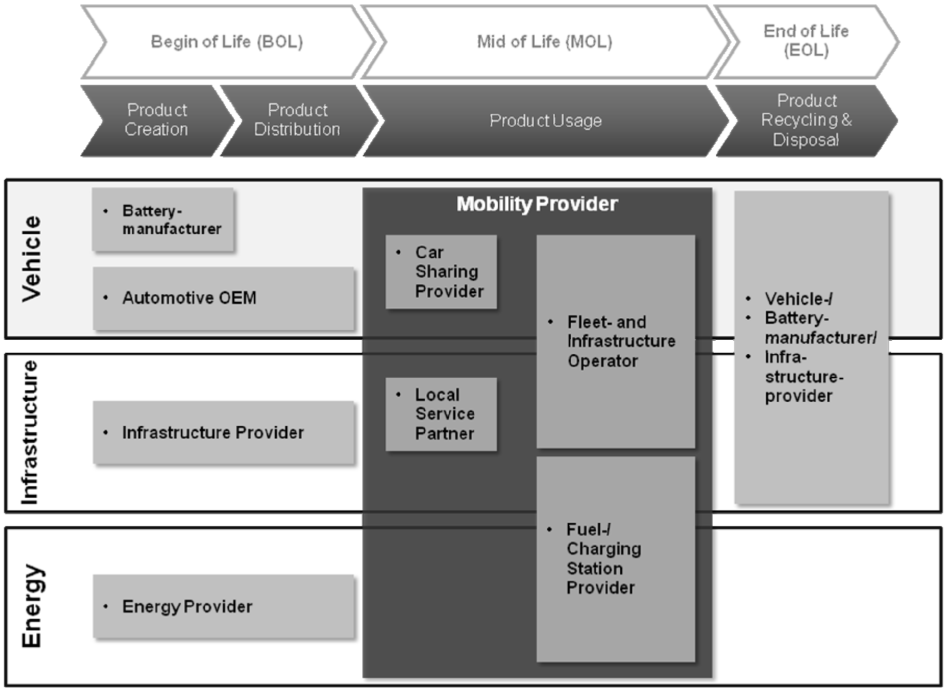

Figure 3: Stakeholders, product life-cycle, player and extended products

This case is based on the collaboration between some and/or all 5 company groups stated in Figure 3. The five identified most relevant organizations which share competences regarding the creation of extended products for e-mobility (battery producer, automotive industry, infrastructure provider, energy providing company and mobility service provider) are shown. The different colors indicate different potential services (tangible or non-tangible) around the core product. As a guiding example, we will use the maintenance and spare part service to demonstrate needed collaboration activities to provide extended products. In the following we will briefly introduce 3 examples:

1. The spare part and maintenance business is very important for automotive OEM and is a part of their general business. In addition to the general services, new products will be offered. For B2B oriented battery producers, spare part or maintenance business is less important, because the direct contact with the end customers is outsourced to the OEMs and garages. Energy providers also enter the market with their core product electricity for driving, but cannot build upon traditional business concepts. Currently, diverse power firms work on new

products and services in the context of e-mobility, such as smart grids, green energy for mobility and car leasing (RWE 2010).

2. An interesting area with probably several links between the five main participants is automotive leasing of electric cars. For automotive OEMs, automotive leasing can be seen as standardized offer. Likewise, more and more mobility service providing companies offer such services. For power firms, leasing offers are completely new and gain in importance. New leasing concepts can be seen as mobility enabling service. Many types can be differentiated such as distance, pool- or full-service leasing packages (Braess and Seifert 2007). So far, leasing offers for electric cars are generally very expensive (MiD 2008). Power firms will have problems to acquire significant market shares, because they have to focus solely on electric cars (Strommagazin 2009).

3. The last example refers to the definition of a battery charging service. This is a completely new service in e-mobility, meaning that none of the companies has positioned itself properly. Consequently, all players might have an interest to enter the market. The power firms begin to offer such services just as a complement to their regular business processes. As already calculated, the additional revenue for charging batteries until 2025 is very low (Mora 2008). The battery charging service is currently not of great interest for the automotive industry, so, no specific offers have been made by those companies. The providers of infrastructure are currently seen as suppliers of the needed equipment. Nevertheless, the infrastructure providers of charging stations could extend their business by operating the infrastructure and selling rights of use.

If the respective interfaces described before are connected by edges, a very complex diagram results. After a more careful analysis, most of the relationships found include the extended products of automotive companies, power firms and mobility service providers. The battery providers play an important role, because their extended products are difficult to connect to the others. Of course, this is a very initial analysis.

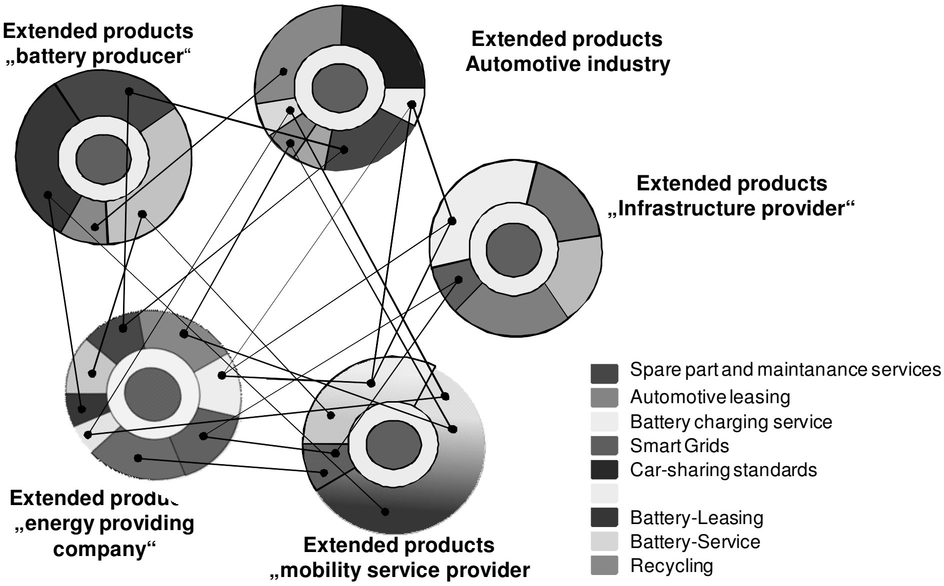

Figure 4: Nodes and edges between the extended products

At this point of time, it's not possible to predict which players will take the lead in the e-mobility market. Nevertheless, we assume that automotive manufacturers will still play a leading role due to their many interconnections and their large market power. The automotive industry faces one of the most difficult transitions in history. The paradigm shift from fossil fuel combustion engines towards electric cars is tremendous (Rothfuss 2009, WIWO 2010). Most of the extended product concepts focus on mobility without ownership, e.g. car sharing. Companies such as BMW experiment with new vehicles in combination with in a car sharing solution (Reithofer 2010). Other companies like Toyota promote combined technologies such as Hybrid (combination of combustion and electrical engines), but also invest heavily in electric cars. It is indeed difficult to foresee if the automotive OEM will lose their competitive position, however, mobility service providers, power firms still depend on the vehicle itself.

The extended product concept shown before, the links between the extended products also identify other areas and cooperation partner options. The use of the business model canvas approach will illustrate one way of identifying new business models.

5 Summary and Outlook

Within this paper the concept of extended products has been introduced. It has been adapted for e-mobility to state the complexity in terms of participating stakeholders and their related business models. The EP model has been slightly modified in order to illustrate services in the different product life cycle phases.

Future work need to be performed on the one hand side in the development of these business models and on the other hand side on the interrelation of business models and their product life cycle impact. As soon as several business models from the MoL phase reach a relevant and critical size they will have influence on the development of vehicles respectively an influence on the BoL phase. A good example is "Better Place" as an infrastructure provider which provides a service with changing stations for electric vehicle batteries (Better Place 2011). If this becomes one of the future infrastructure providers and operators car manufacturers need to take the switch technology for a battery and the battery itself (size, form factor, interface) into account. Also car sharing or mobility services influence the vehicles due to different requirements of owning a car.

Acknowledgment

This work has been partly funded by the BMBF project PMC – Personal Mobility Center. The authors wish to acknowledge the BMBF for their support. We also wish to acknowledge our gratitude and appreciation to all the PMC project partners for their contribution during the development of various ideas and concepts presented in this paper.

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Exploiting Product and Service Lifecycle Data

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Abstract: The product lifecycle comprises the product design, digital factory and service sub lifecycles. The outcome of the product design lifecycle is the translation of the product idea and associated requirements into a digital design model of the envisioned product. The digital factory lifecycle encompasses testing and optimizing production processes in order to reduce the time from product idea to a finished product and to digitally simulate and improve the factory processes before their actual deployment. The service lifecycle includes all activities of operating the product, often offered as Product Service Systems (PSS) that provide products together with bundled services. Unfortunately, data captured during the service sub lifecycle like sensor generated and human knowledge data is isolated and not fed back into the product and factory design sub lifecycles. In order to integrate these sub lifecycles, we analyze data flows between the sub lifecycles and identify typical usage scenarios for real-time exploitation of authentic service data which lead to an overall improvement of the product lifecycle. Finally, we discuss implied challenges to preservation and real-time exploitation of integrated product and service lifecycle data.

Keyword: Product and Service Lifecycle, Sensors, Digital Factory

1 Introduction

Globalised markets, changing customer demands, product variant support and stronger environmental regulations require continuous process changes, quick innovations and strong decrease of planning and engineering times for competitive companies. To achieve these goals, the product design and its manufacturing process need to be integrated. This was the basic goal of Concurrent Engineering and led to a digitalization of the production process, culminating in the concept of Digital Factories [2] which allow the simulation of production plants in order to optimize manufacturing processes and supply chains [8].

The product lifecycle is a composition of three (complex) sub lifecycles: the design, the factory and the service (or operational) lifecycle. Whereas data generated during design and manufacturing is often integrated, data about the operational use of products is not linked to other sub lifecycle data. Due to the variety of stakeholders involved and the physical distribution of products, the semantic integration with the other phases is still a challenge. Currently, in most cases the monitoring of the product and the capturing of information stops after the product has been sold to the customer. On the other hand, increasingly more information is captured during the product service by embedded sensors and due to new business models where the product use is sold rather than the product itself by providing Product Service Systems (PSS) there exist more possibilities for capturing service product data, even for mass products. Therefore, we argue in this paper that the service sub lifecycle represents an integral constituent of the product lifecycle; hence the service data which is captured during the usage needs to be made available in a structured way for improving the design and manufacturing of the product.

The following section describes the sub lifecycles in more detail and put special emphasis on the generated data. We are particularly interested in the product service phase where more data can be exploited both for operating the product and for improving the design and manufacturing processes. Then we identify a number of usage scenarios where data flows from one phase to another product lifecycle phase. Finally, we describe challenges which have to be overcome to support an exploitation of sub lifecycle data.

2 The Product Lifecycle

The product lifecycle spans from idea generation, development, process planning, production, operation, service to disposal [4]. The product lifecycle (Figure 1) includes the product design, product manufacturing and product service (operational) sub lifecycle. Since the product design and factory design is executed in parallel, they are clustered into the manufacturing process block. Flows of data between the sub lifecycles are described in more detail in section 3. Now we characterize the sub lifecycles:

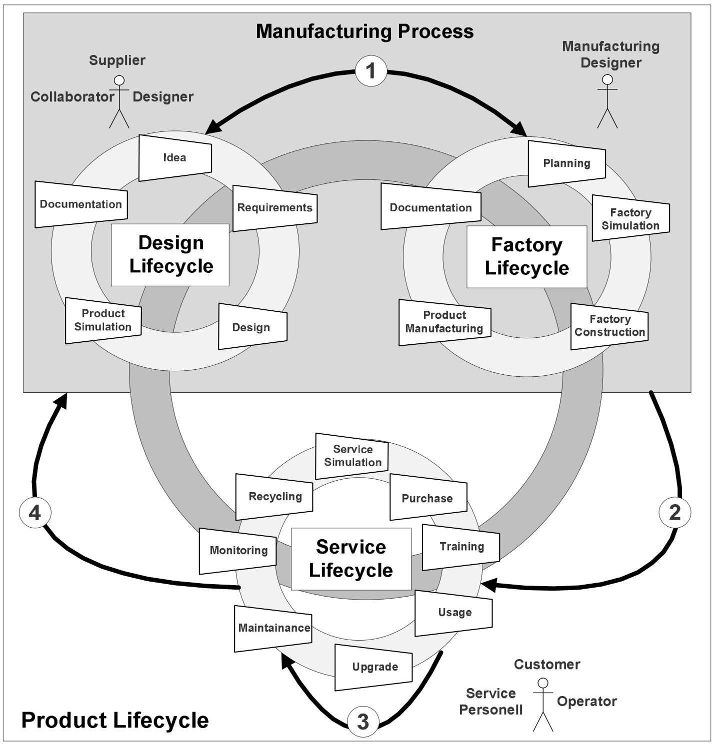

Figure 1 The Design, Factory and Service Lifecycle

Design Lifecycle: The design lifecycle starts with innovation processes that capture the initial product idea and requirements. The actual product design is performed through domain and enterprise collaboration, co-operations between virtual organizations and different engineering domains. *Product Data Management* (PDM) systems support data exchange between the design tools whereas *Product Lifecycle Management* (PLM) systems support the design tool integration [3] with tools like *Enterprise Resource Planning* (ERP), requirements engineering, etc. During the design lifecycle, different "documents" are created which are related to the different design phases. Depending on the industry branch, specific phases are part of a design lifecycle. For example, in Printed Circuit Board (PCB) design, the following steps are executed: component library creation, schematic capture of component list and their connections (*netlist*), component placement and routing as well as circuit simulation. In other design areas (mechanical design, system design, etc.), other specific data is generated according to the necessary process steps, like geometry, functional and simulation models, etc. Finally, during product design a variety of knowledge is created [1] (design rationale, constraints, history, review) including collaboration data of actors involved (votings, discussions, decisions, etc.). Finally, often references to standard product classifications are created in order to describe the properties of product components.

Factory Lifecycle: A digital factory is a virtual representation of a real factory based on a digital design model of all resources and processes (e.g. automotive or aircraft industry) of the factory. It can be used for modifying a manufacturing process, either due to new requirements or for efficiency improvements. The factory model covers supply chains, processes, workplaces and employees that are required for product production. By using digital simulations, the manufacturing process can be optimized without investing in production materials and without affecting the current production. To describe the whole production process, the manufacturing model also must contain the description of a number of non-technical processes (e.g. logistic processes modeling the material flow).

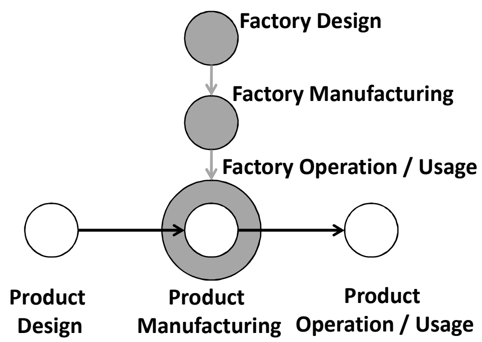

Figure 2 Interleaved processes of product and factory design

The factory lifecycle (Fig. 2) has a similar outlook as the overall product lifecycle since it starts with the product design and its digital simulation and testing, before it is physically manufactured and then used by customers. In parallel to the product design also product manufacturing has to be planned and designed. This may result in the building of a complete factory (e.g. for a car series) or in the adaptation of existing devices, e.g. by creating robot programs or by producing specific dies for a die forging production line.

The "product" of the factory lifecycle is a factory which can produce the actual product. The actual product is then manufactured by entering the operational phase of the factory.

Whereas the data which is generated in the design and manufacturing phase is mostly related to the concept of the product, during the operation of the digital factory, various product instance-specific data has to be produced as a result of creation of the instance, e.g. time and production line where it has been produced and many other data which allow to trace the product to its exact manufacturing environment. This information might become important during the use and disposal of the product.

Service Lifecycle: In particular for mass products, the service lifecycle is quite separated from the other lifecycles, and it is still difficult or not yet possible to capture data from the operational phase due to non-existing technologies and processes. However, some companies do no longer focus on selling products alone. Instead, services around the product are offered as *Product Service Systems* (PSS) [7]. The key idea behind PSSs is that consumers do not specifically demand products (as tangible assets), but rather seek the utility of these products. A physical automobile or a power plant customized by intangible services (e.g. maintenance, training, operation and disposal) is an example of such product and service combination. By using a service rather than a physical product, more customer needs are met with lower material and energy requirements, since PSSs enable manufacturers and customers to decrease their service costs through cooperation.

One PSS example is a mobility service including recycling. The service transportation (measured in usage hours) may be provided by a car manufacturer to a customer rather than the product ownership. This implies the responsibility of the manufacturer for maintenance and recycling which enables both the customer and the producer to decrease their costs if detailed information about the status and usage of the car fleet is available.

Service lifecycle data corresponds to different underlying information models:

- As-built-model: exact information about the manufacturing of the single product instance (Material, configuration, subcomponents)
- As-maintained-model: reflects all modifications which have been done during maintenance, e.g. replacements of components by other components
- As-operated model: contains information about the operation, e.g. number of kilometers on paved roads and on dirty roads, current state of brake pads, etc.

An important aspect for data to follow up products over the service lifecycle is the quantity in which a product is produced and also its customization. Some products are unique (i.e. only one product instance exists), e.g. factories or power plants. Other products are produced in big quantities (nails and screws). For a power plant a lot of operational data is captured which is usually not done for a single screw.

Further information is maintained during the operation and service of a product. After its deployment, users need to be trained in order to operate a product. During the training phase, immediate feedback can be collected manually from users or service personnel. Furthermore, operating data may be recorded automatically by sensors in order to improve usability and reliability, but also to test whether the product operates within expected parameters. A driving or flight simulator model is an example for illustrating the complexity of data which might be needed for the training phase.

3 Product Lifecycle Data Flows

Various data flows can be observed between the different sub lifecycles of the product life cycle (see Figure 3). We have put design and factory into one box, since very often it is not visible for the outside whether data comes from design or manufacturing or whether data flows to design or manufacturing. Design internal and manufacturing internal flows are out of scope here. Hence, four different data flows are of interest:

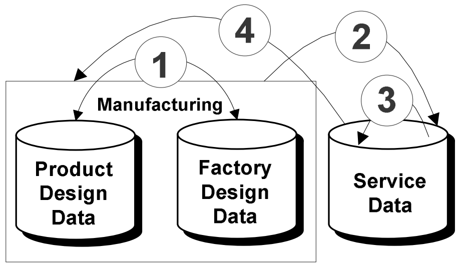

Figure 3 Data Dissemination from Design, Factory and Service Lifecycle

1. Factories and products are designed simultaneously by using distributed processes and data. Collaboration takes place within the same or across different companies. The factory designer receives data (like product part specifications) from product design and creates and optimizes manufacturing processes. If manufacturing simulation reveals problems, the product designer needs to get feedback and has to adapt the design.
2. After the product has been manufactured, it is delivered to the customer or operator. During this hand over, important data flows between the two sub lifecycles. Service and training personnel receive product documentation (e.g. initial training material) and specific product instance meta-data (e.g. serial number) is transferred to service actors.
3. Service providers need information about the product usage to improve their services, e.g. by planning maintenance in time, ensuring availability of spare parts, replacing products before they stop working, providing up to date training and maintenance material, etc. Their goal is to improve the product availability while decreasing the costs.
4. Data that is created during service and operation can be fed back into the product design process to support product redesign or variation. In addition, product service lifecycle data might have ecological and economic influence on the product design and hence on the evolution of the manufacturing and digital factory processes themselves.

4 Product Life Cycle Data Usage Scenarios

This section describes usage scenarios for the four data flows described above.

Manufacturing Data Circulation: Product design data models include a detailed digital mapping about the envisioned product. For example, the model contains a list of parts of the product including its geometry. This data is delivered into the digital factory data model to support authentic simulation of the factory and manufacturing processes. If such simulation of supply chains or manufacturing reveals inefficiency, data and knowledge from the digital factory design flows back to the product design and may lead to product model adaptations.

Product Meta-data delivery: Three examples illustrate the flow of relevant product knowledge (meta-data) from manufacturing to the service lifecycle:
Human and machine based training enactment: Before a product is operated, the customer and service personnel must be educated about the product features. For example, an aircraft captain must be aware of airplane specific features or a flight simulator must be fed with the actual behaviour of the airplane.
Legal and technical part replacement constraints: Some parts of the delivered product might have usage or replacement constraints that have to be considered during the service lifecycle. For example, if a product part is replaced by a part from a non-authorized manufacturer, the customer might lose warranty or even the operating license. Service personnel must know about these constraints and compliance must be checked.
Product customization meta-data delivery: As products are targeted for product service systems, they are customized based on customer demands. These customization information need to be delivered to the service actors in combination with default product and manufacturing meta-data, like workplaces that manufactured the product etc.

Process Improvement: When sensor data monitors product status information in real-time, it can be broadcasted to the vehicle manufacturer. If the vehicle manufacturer could collect such information from a big amount of cars, maintenance scheduling can be planned more efficiently. For example, during regular usage the product status could be continuously monitored and data about its status and environment according to pre-constructed dimensions could be provided to registered recipients. Such data can be related to controlling the operation of the product, e.g., performing specific actions (modification of altitude of an aircraft, automatic braking of a car) or for diagnostic purposes and proper maintenance.

Further process improvements apply to simulation models, since the manufacturing process (factory and design lifecycle) includes a simulation phase which benefits from real-life service data. For example, factory and product design simulations assume specific materials of the product parts. If a product part must be exchanged during service, these changes have to be incorporated into simulation models. While noticing this defect, it is unknown whether this is a problem of the product design or a manufacturing problem which needs to be examined.

Finally, the service process aims for the reduction of waste, emissions and energy consumption. Therefore, it is worthwhile to simulate and optimize service and recycling processes so that service data can be used to *calibrate service process simulation models* which lead to decreasing costs as an advantage both for customers and manufacturers. In addition, the targets of new environmental regulations would be met, which could include resource consumption reduction and protection of environment. Here, valuable service and recycling process simulation input is delivered by service data.

Real-time exploitation of sensor service data: sensor enriched products (*intelligent products* [9]) are able to collect and handle usage information (tracking and tracing the origin, location, movements) and to react on it proactively by using low cost radio frequency identification (RFID) and wireless communication technologies. For example, modern vehicles contain multiples sensors that monitor various aspects of the engine's operation (temperatures, fuel flow rates, etc.). This data is not only interesting for the driver but also for the service company since over a long time period, this enables to record and to report the history of a product. If such sensor data is broadcasted, it can be shared in real-time with actors in all phases of the product lifecycle. Data obtained from sensors during product service can be exploited for three different example scenarios:

Product diagnostics: detecting needs for maintenance or repair in advance, identifying and reporting conditions proactively before a failure occurs, ordering spare parts and scheduling service personnel [5].

Variance analysis and problem alerting: by monitoring sensor data, critical parameter values that are beyond simulation model parameters can be detected. Such critical values have to be reported in real-time as feedback for the operator (e.g. as input for flight simulator models) by executing rules that may give alarm or trigger other events. It also can be collected and later on transmitted to the manufacturer.

End-of-life management: Due to a decrease of natural resources which are required for manufacturing, environmental regulations demand that during recycling the product is disassembled and all parts are recycled according to the regulation. However, the product parts may not be those which were originally equipped by the manufacturer because during operation parts may have been replaced by the customer or by service personnel. In addition, during recycling the wear and tear of the parts and the severity of contamination is unknown. However, this knowledge is required to enable recycling which is compliant with legal and environmental regulations. Fortunately, the complete history of the conditions of product parts can be delivered by product integrated sensors ready to be used by a product recycling service [10].

Real-time exploitation of knowledge service data*:* The product service involves various actors which create and exchange knowledge that can be used to improve service quality, e.g. on the internet as a searchable knowledge base to support decisions. Also, service data can be exploited to derive new or unforeseen product requirements for future product variants that increase customer satisfaction. Two different sources exist:

Tacit requirements: Products are designed according to the requirements of customers. However, the real-world product usage might be different from the usage that was previously envisioned. For example, a product part might not be used at all or it may be used in a different way than previously thought. By using sensor data, the real product usage can be detected and recorded.

Explicit customer knowledge and demands: During the operation of a product valuable data is generated by human (product owner, mechanic) around collaboration processes. Software can be used to make requirements explicit.

5 Challenges for Product Lifecycle Data Exploitation

Unfortunately, the usage scenarios described above are rarely put into practice yet. It is still difficult to practically support such an integrated view of the various life cycles and the seamless flow of information from one phase to another. Therefore, we describe various challenges that have to be addressed for supporting these usage scenarios.

Semantic Integration: Product lifecycle data is distributed across different barriers:

- Various *sub lifecycles* exist in the whole product lifecycle.
- Human and machine *actors* generate product data in each sub lifecycle.
- Product lifecycle data is exchanged between different *systems*.
- Human actors use different *devices* for generating product lifecycle data.
- *Tools* generate heterogeneous formats according to proprietary and open schemas.

- As products are in operation for several decades, product lifecycle data conforms to schemas that grow apart and *evolve over time*.
- Cooperating *organizations* execute different processes
- (Virtual) organizations are *geographical distributed* around the globe.

Independently generated product data has to flow across these barriers. For example, a flight simulator must be fed with model parameters from the manufacturing lifecycle. However, the simulator may be built by a different company than the manufacturer itself. These intrinsic semantic relationships between design, manufacturing and product service data exists despite the distribution of data. Semantic integration enables to logically integrate across barriers and it enables interoperability by contextualization of distributed lifecycle data. Interoperability supports collaboration of actors, tools, systems, devices, etc. by using an integrated lifecycle data model that is annotated with meta-data that conform to special vocabularies. By using domain specific vocabularies, it is possible to extract meaning from lifecycle data as well as understanding and reusing archived product lifecycle data in the near-term and long-term future.

Persistent Product Identification: One special challenge for semantic integration is the identification of products across barriers (e.g. lifecycles, tools and systems). All generated product lifecycle data need to be associated either to a specific product instance or to the product concept instance that describes the product in general. For example, products need to be identified for simulation and maintenance across lifecycles. Special mapping definitions or registries help to identify products across these lifecycle barriers by establishing a non-changing persistent product identifier.

Active Service Data Processing: Captured service lifecycle data consists of sensor and collaborative knowledge data that needs to be processed in order to support reuse (e.g. decision making) which lead to three challenges.
Sensor data inferences: sensors only deliver raw time series values. To support real-time product diagnostics, it is necessary to derive higher-level of understandings. Such sensor data inferences have to be described by rules that are able to trigger alarms if specific product conditions arise which lead to human based decision making.
Product knowledge reuse: In addition to sensor data, valuable human tacit knowledge is used during product service including knowledge stemming from customers and service personnel. For further reuse, such knowledge must be published to create a publically available real-time knowledge base for products that grows by time. In addition, that data has to be fed back to users so that they can benefit from sending information.
Product data aggregation: Active service data processing also occurs, when manufacturers are informed about malfunctions of their products. A generic notification and problem alerting service can be used. During such notification, product service systems have to execute a data aggregation process that bundle and communicate all relevant data and meta-data in order to enable product improvements.

Data Provenance: Factories themselves are complex and long life products which have to be adapted to the needs of markets, production variants and technology innovation. It is necessary to document the digital factory provenance because during an investigation of problems in production processes the history of the factory can easier be analyzed if it is available as digital data in contrast to paper based archival exploitation which tend to be tedious and error prone. The provenance of data [11] includes the social context (who), rationale (why), process (what) and time (when). This data provenance can be externalized by machine readable knowledge representation languages. Data provenance is especially important during planned and ad-hoc collaborations between lifecycle actors that are executed while data flows between sub lifecycles or within a lifecycle:

- Collaboration between engineers from the electrical and mechanical domain who exchange placements constraints which leads to archival relevant decisions.
- Collaborative decision processes during manufacturing include the transformation of product design data into digital factory configurations as initial requirements.

Since these decision processes are non-trivial and time consuming, they should be archived for history tracking and future reuse by capturing the provenance of data. Beside automatic meta-data extraction, humans involved in collaboration processes should be urged to annotate process data immediately and simultaneously with the creation of source data, since such data cannot be memorized and recreated.

Data Security and Actor Privacy: The whole product lifecycle is executed by distributed and collaborating companies. Since virtual organizations are sensitive to a protection of their data from unwanted exchange with collaboration partners (intellectual property rights protection), the product data model should allow the description of right protections for specific parts of the data. Also, several different actors (e.g. customer, service personnel) are involved and data may be collected automatically. It must be assured, that the actor privacy is guaranteed which is especially important, when customer data is transferred to the manufacturer. Therefore, an agreement needs to be established between customer and manufacturer that assures that only relevant and sender approved data is transferred.

Policy Enforcement: Specific knowledge about the product specifications and restrictions are delivered from manufacturing to service processes. Such know-how might include rules that ensure that technical constraints are really met during service. These legal and technical constraints about product parts need to be described in machine readable representations so that their compliance can be checked automatically to enable triggering alarms in case of misuse.

Data Analysis, Archival and Preservation: Since service lifecycle sensor data arrive in high frequency, special archiving systems are needed which are capable of handling such large amounts of data. To generate further insights into the collected data, mining algorithms can extract relevant patterns from data. Since a product may be in operation for several decades, technologies, formats and data models will evolve. To support this evolution, special methodologies are needed to keep the (meta-)data interpretable [4].

6 Conclusion and Outlook

This paper described the design, factory and service sub lifecycle and the data flow between these sub lifecycles. Several usage scenarios showed quality improvements for all lifecycles if product lifecycle data is exploited. To support this product and service data exploitation, several challenges have been described which need to be addressed.

As described, semantic integration helps to understand the captured product lifecycle data across different barriers. Future work will evaluate appropriate machine readable formal representation languages like lightweight ontologies and their publishing, querying and visualization. Special interest will be put on the evolution of archived database schemas, XML documents and ontology based PLM data. In addition, it has to be evaluated, if process definitions can be extracted from ad-hoc collaboration processes and where hidden social network knowledge can be exploited for future process execution. Social network knowledge can be used to extract relevant topic experts during future social collaborative search [6]. Attention will be put on grid-based technologies that were, for instance, developed in the SHAMAN project [12], and it will be evaluated if these technologies support efficient archival of large amounts of high frequency sensor data. Since processes and requirements may differ in different industries (e.g. automotive, aerospace or engineering), domains, companies and even projects, future work will evaluate requirements of different industries. Finally, this paper only described some data flows between the sub lifecycles. Future work also includes a further analysis of the control flows among the different lifecycles which may reveal additional data flows.

Acknowledgment

The research described is related to and partly funded by the European Commission's 7th Framework Programme in the integrated project SHAMAN.

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Information model of ship product structure supporting operation and maintenance after ship delivery

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Abstract: Recent trends in the engineering information management technology of the shipbuilding industry are characterized by the spread of the product lifecycle management (PLM) concept and an increased demand on better use of ship engineering data after ship delivery. Product structure data, explicit hierarchical assembly structures representing assemblies and the constituents of those assemblies, form the backbone of all engineering data managed by PLM systems. The product structure differs depending on the industry's requirements, design and manufacturing methods, or lifecycle phases covered. In this study, information model of ship product structure is developed particularly considering the use of ship product structure data at the phase of operation and maintenance after the delivery.

Keyword : Information model; ISO 10303 STEP PDM Schema; ISO 15926 Process Plants; Operation and maintenance; Ship product structure.

1 Introduction

Product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal, and is also a business strategy of a company [1]. Product structure data, explicit hierarchical assembly structures representing assemblies and the constituents of those assemblies, form the backbone of all engineering data managed by PLM systems. The product structure differs depending on the industry's requirements, design and manufacturing methods, or lifecycle phases covered [2].

Recent trends in the engineering information management technology of the shipbuilding industry are characterized by the spread of the PLM concept and an increased demand on better use of ship engineering data after ship delivery. In order to meet this requirement, shipbuilding computer-aided design (CAD) vendors have developed PLM systems. Large shipbuilding companies in Korea are either customizing PLM systems developed for use in the mechanical industry or developing new PLM capabilities which are based on ship CAD systems in use. It is interesting that large shipbuilding companies in Korea adopted mechanical PLM systems in spite of interoperability issues with ship CAD systems.

The shipbuilding industry in Korea has attempted to apply the PLM concept, focusing on managing the product data at the early lifecycle stages including design and manufacturing; the main purpose of introducing PLM systems is to seamlessly integrate CAD and enterprise resource planning (ERP) systems through PLM systems. However, in the cases of floating production storage and offloading (FPSO) and drill ships, 90% of the total lifecycle cost is incurred at lifecycle phases after ship delivery. Furthermore, effective operation and maintenance (O&M) and recycling of ships are gradually becoming important due to increased regulations on eco-friendly ships as well as ship safety. For these reasons, PLM systems are needed to provide capabilities so that ship data generated at design and manufacturing phases are efficiently utilized at lifecycle phases after ship delivery. Since core information managed by PLM systems is product structure, information model of ship product structure that is able to support ship O&M works is required.

In this study, information model of ship product structure is developed particularly considering the use of ship product structure data at the O&M phase after the delivery. To this end, information requirements of ship product structure are analyzed and then information model of ship product structure is defined according to the requirement. Usability of the proposed information model is demonstrated by representing various types of product structure data with this model.

2 Related literature and studies

2.1 Information modeling of product structure

Bill of material (BOM) is a term similar to product structure. BOM is a hierarchical assembly structure of parts constituting a product. When multiple instances of a part are used in an assembly, only one relation between the part and the assembly is defined. The number of instances is associated with the relation as an attribute. The product structure is also a hierarchical assembly structure of parts constituting a product. However, when multiple instances of a part are used in an assembly, multiple relations, equal in number to the instances between the part and the assembly, are defined.

Van Veen and Wortmann proposed a generic BOM management system based on the variant concept [3]. Olsen studies an information model which represents product family with programming languages [4]. Do et al. suggested a method to represent engineering change information by using product structure data [5]. Trappey and Lin developed an object-oriented BOM system for the management of product family [6]. Kim et al. studied the management of BOMs in ship outfitting design [7]. In this study, types of information that should be contained in BOM data and capabilities that shipbuilding PLM systems should provide are elaborated with several cases. Kim et al. suggested the system architecture as well as BOM data processing functionalities and the procedure of a collaborative BOM management system for small and medium enterprises [8].

Most of previous studies are on configuration management in which several products constituting a product family are constructed and managed with product structure. They mostly focused on the mechanical industry and did not consider the O&M phase. Kim et al. [7] studied the management technique of BOM data in the shipbuilding industry. However, they dealt with product structure not in information model level but in data (or instance) level focusing on the use of product structure in the design and manufacturing phases.

2.2 Related industrial data standards

Typical industrial data standards for the representation of product structure are STEP product data management (PDM) schema [9], ISO 10303 STEP AP239 product life cycle support (PLCS) [10], and ISO 15926 Process Plants [11]. The shipbuilding industry occupies an intermediate position between the mechanical and plant industries. ISO 15926 Process Plants is an appropriate international standard for the plant industry, whereas ISO 10303 STEP is suitable for the mechanical industry. In this study, the authors referred to the STEP PDM schema and ISO 15926 Part 2 data model in order to develop information model of ship product structure.

The STEP PDM schema is a common PDM data schema developed by PDES, Inc. and ProSTEP, Inc. It is a real subset of PDM-relevant STEP APs (AP203, 212, 214, 232, 233, 239), fulfilling nearly all requirements for PDM data exchange. It provides main functionalities for parts and documents: part identification, product structure, document identification and linking the identified documents to the product structure, versioning, and product configuration.

ISO 10303 STEP AP239 PLCS, an extension of the STEP PDM schema, is an international standard designed to ensure that the support information is aligned with the evolving product definition over the entire lifecycle. It provides information resources for support engineering, resource management, configuration management, and maintenance and feedback.

ISO 15926 Process Plants is an international standard for data sharing and integration of process plant lifecycle data. From the view points of product structure, ISO 15926 Part 2 data model does not provide enough information resources for engineering change management and configuration management, but it has information resources useful in the O&M phase including clear definitions of classes and individuals, discrimination of functional and physical objects, and integration of space and time dimensions.

3 Information requirements of ship product structure

3.1 Lifecycle phases before ship delivery

Contrary to mechanical CAD systems, shipbuilding CAD systems partially have PDM capabilities: access control, workflow management, and part catalogue management. Due to this reason, advantages of applying PLM systems in the shipbuilding industry come not from conventional PDM capabilities but from capabilities for seamlessly integrating whole lifecycles. Therefore, not only conventional application fields of product structure at the design and manufacturing phases, but also tight integration of product requirements created before the design phase and product structure [12], and use of product structure for the O&M works are required.

Views on the same product are different from each other depending on lifecycle phases or application purposes, which lead to different product structures for the same product. To describe the difference between product structure and product view, product structure contains explicit hierarchical assembly relations among constituents of a product whereas product view is product structure constructed relevant to the requirements of a particular lifecycle stage and application domain.

In the shipbuilding industry, different product views are required as ship design proceeds, as shown in Fig. 1. Ship product structure evolves from a rough one to a detailed one: from the main machinery list (MML) in the early design phase, through the system-oriented product view in the preliminary design phase and the block-oriented product view in the detail design phase, to the zone-oriented product view in the manufacturing design phase [7]. Therefore, information model of ship product structure should support product views.

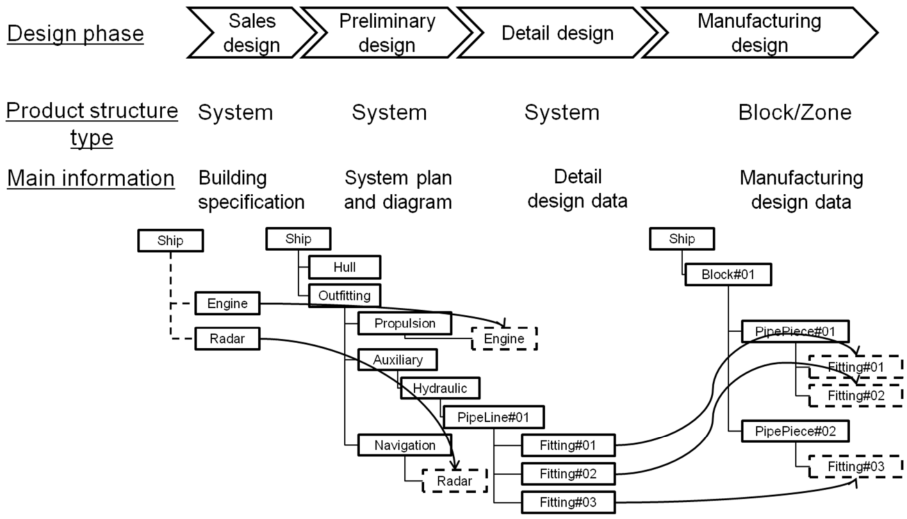

Fig. 1. Evolution of ship product structure – before ship delivery

An engineering change can be defined as all the changes made to the product structure, product configuration, or part properties with the aim of improving functionality, quality, or productivity of a product. From the viewpoint of the product structure, an engineering change implies a change in the hierarchical relations in the product structure, which is caused by addition/deletion/modification of parts. In the design phase, engineering changes are frequently made due to technical problems. After a design is finalized and released to manufacturing departments, requests for engineering change are also made due to manufacturing or in-service issues. In order to manage the change history of parts constituting a product structure according to engineering changes, version and revision numbers are assigned to part and document objects, respectively. Shipbuilding industry needs tracking of engineering change history or reuse of design data, hence, information model of ship product structure should support version management.

Configuration management is a PLM capability where a part family is constructed in such a manner that interchangeable parts with standard interfaces and their combinations are defined in order to satisfy the requirements of various users. A part family constructed with product structure is called product configuration. A product structure is usually the representation of the physical composition of parts constituting a single real product. However, when the concept of configuration management is introduced, a product structure represents all the possible compositions of parts for individual products of a part family. Interchangeable parts are called options, while individual products of a part family are called variants.

In the shipbuilding industry, configuration management may be necessary for managing the product structures of series ships. However, conventional configuration management capability of mechanical PLM systems was developed under two assumptions [13]; all parts and product structures constituting a part family are clearly identified in advance and interfaces of mutually interchangeable options in product configuration are identical. However, when designing a series ship, it is practically unfeasible to consider the product structures of other series ships to be developed in the future and to make interfaces of options identical for series ships, since series ships have different points of design time and shipbuilding companies typically adopts engineered-to-order (ETO) manufacturing strategy.

A ship assembly consisting of millions of parts requires huge data storage to PLM systems. And to make things worse, even though more than 90% parts of series ships are the same, all the product structure data for every series ship are stored in a database. This is because presently, ship product structure data are modeled on the basis of the “copy and modify” approach where all product structure data are copied first and then some of the product structure are modified to meet new requirements of a new series ship. This leads to a problem of redundant use of data storage. Information model of ship product structure should provide information resources to solve this problem.

3.2 Lifecycle phases after ship delivery

Before analyzing information requirements of ship product structure in the lifecycle phases after ship delivery, it is worth comparing abstraction level of product structure data used in the design/manufacturing phases with that of product structure data in the O&M phases. Objects represented in product structure in the design phase are classes, abstract objects which do not exist in the real world. They specify shape, physical characteristics, and functional characteristics that members (or individuals) of a class must have, such as *centrifugal pump type A* in Fig. 2. On the other hand, individuals which exist at specific time-space in the real world should be managed in product structure in the O&M phase in addition to classes. For example, it is required to monitor and trace installation time, repairing history, and current status of a real *pump with tag number 0000001* of Fig. 2.

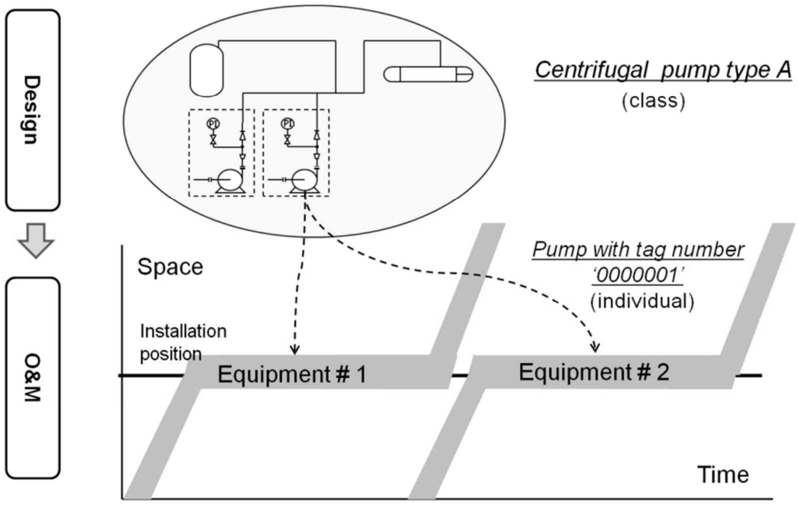

Fig. 2. Distinction between class and individual

In the O&M phase, after O&M master plan is first established from design and manufacturing data of a product, O&M works are performed according to this master plan, of which history is also managed. The O&M master plan links to class-level product structure while the O&M history connects to individual-level product structure, as shown in Fig. 3. Therefore, information model of ship product structure should support both class- and individual- level product structures and couple them together.

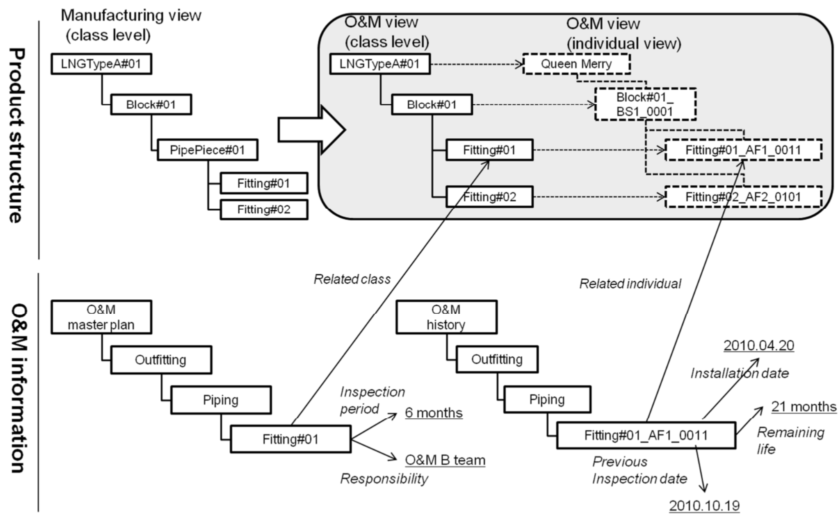

Fig. 3. Use of ship product structure – after ship delivery

4 Information model of ship product structure

Information model of ship product structure is defined by referring to the information requirements mentioned in the previous section, and various types of product structure data are represented with this model in this section. Information model of ship product data is proposed in Section 4.1 and the authors represent various cases of ship product structure data shown in Fig 1 and Fig. 3 in Section 4.2 using this model.

4.1 Definition of information model of ship product structure

The proposed information model of ship product structure is shown in Fig. 4. This figure is diagramed in EXPRESS-G [14]. Entities of this information model are mainly divided into *abstract_object* and *individual*. The authors referred to ISO 15926 Part 2 data model for the discrimination of classes and individuals. The *abstract_object* entity is used to specify class-level objects and relationships and the *individual* entity is used for representing individual-level objects. There are two types of relationships; the *class_of_relationship* entity specifying the relation between classes and the *relationship* entity representing the relation between individuals.

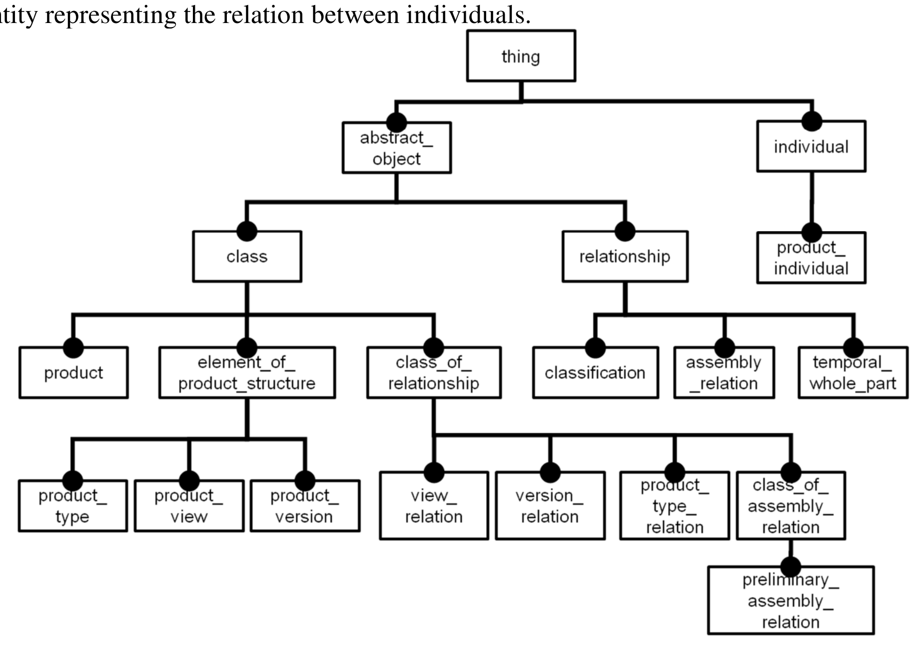

Fig. 4. Information model of ship product structure supporting operation and maintenance

The *product* entity is an assembly or a part of class-level product structure. Whether the instance of this entity is an assembly or a part is specified by the *product_type_relation* entity. The assembly hierarchy between parts is represented by the *class_of_assembly_relation* entity. When detail hierarchical relationships between parts constituting a high level assembly are not fixed but promissory usage relationships between parts and the assembly that is not the immediate parent in the hierarchy are known, the *preliminary_assembly_relation* entity is used to represent this assembly hierarchy.

In order to specify product version and view, the *product_view* and *product_version* entities are defined by referring to STEP PDM schema. The *product*, *product_view*, and *product_version* entities are linked by the *view_relation* and *version_relation* entities respectively.

Members of a certain class are declared with the *classification* entity. The assembly hierarchy between individual parts is represented by the *assembly_relation* entity. Since individuals exist uniquely in the time-space and do not change, they do not have different views and versions. Therefore it is not necessary to provide information resources for representing views or versions in individual-level product structure. However, role, usage, or classification of an individual at a particular period of time can be changed. It is called temporal part (or substate) of the individual. The *temporal_whole_part* entity represents this relationship between an individual and its temporal part.

4.2 Use of information model of ship product structure

To show case studies of the proposed information model, a new diagram, where instance data adhering to the information model are added to the EXPRESS-G diagram for the information model, is used. In this diagram, instance data of an entity is written in underlined italic font. For example, *PipeLine#1* and *Fitting#1* in Fig. 5 are instances of the *product* entity.

The hierarchical (assembly) relationship between *PipeLine#1* and *Fitting#1* shown in Fig. 1 is represented as Fig. 5. *PipeLine#01* and *Fitting#01* are declared as assembly and part respectively and their hierarchical relationship is represented by the *class_of_assembly_relation* entity.

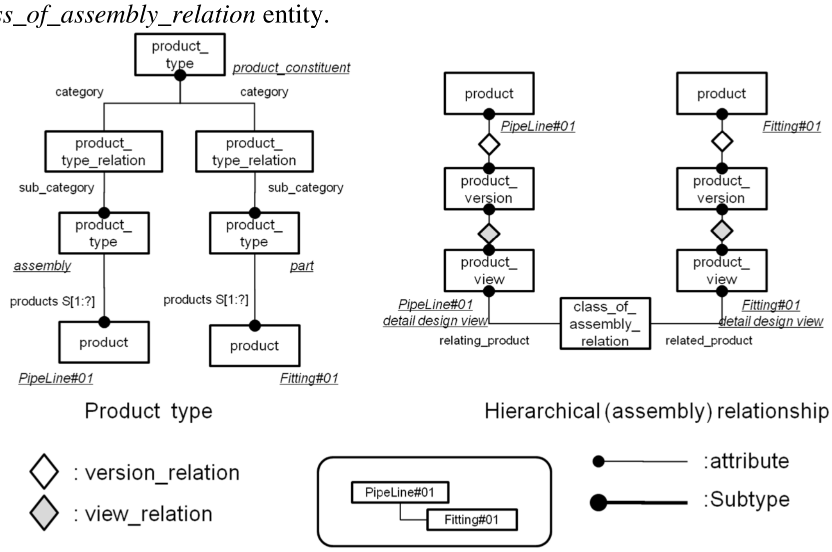

Fig. 5. Representation of hierarchical relationship between parts constituting a product

Different product views of *Fitting#01* shown in Fig. 1 are represented as Fig. 6. After *Fitting#01* is specified with the *product* entity, detail design and manufacturing design views are represented by *product_view* entity.

At the sales design phase, if a component is lined in MML, it means that this component is chosen but its exact position in product structure is not fixed. This kind of hierarchical relationship is represented by the *preliminary_assembly_relation* entity, as shown in Fig. 7. In this figure, *Type B* engine is chosen for the design of *LNGTypeA#1* ship.

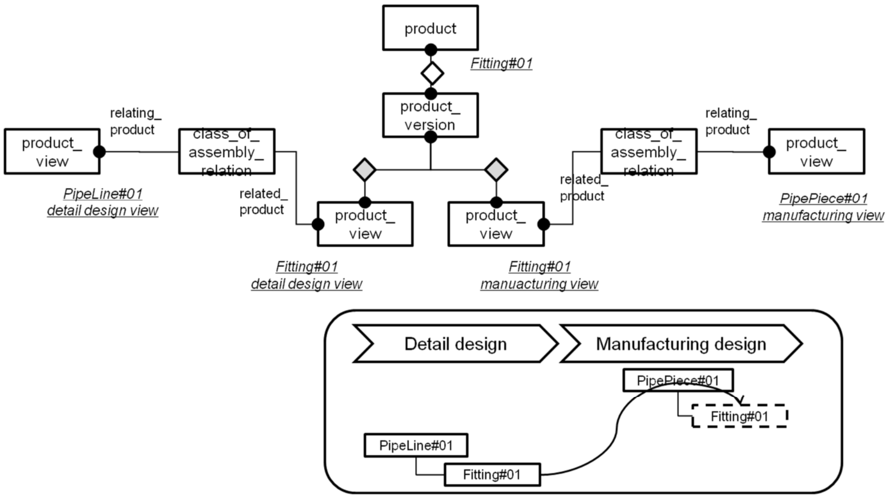

Fig. 6. Representation of different product views

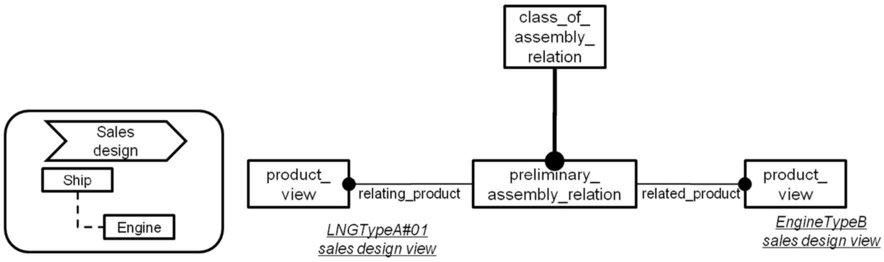

Fig. 7. Representation of a part of which exact position is not fixed in product structure

When some of product structure of a ship designed at point of time T is to be reused for the design of another ship designed at point of time $T+\alpha$, the instances of *product_view* for parts or assemblies, which will be reused, are referred to for the definition of both of product structures of two ships. For example, if *PipePiece#01,* which is a component of *Block#01* assembly of *LNGTypeA#1* ship, is to be reused for the design of *Block#01'* assembly of *LNGTypeA#2* ship, additional assembly relationship between the detail design view of *PipePiece#01* and the detail design view of *Block#01'* is specified, as shown in Fig. 8.

The *classification* entity is used for the connection of class- and individual-level product structures used in the O&M phase. For example, *Fitting#01_AF1_0011* individual part installed in *QueenMerry, LNGTypeA#01* type ship, is declared as member of *Fitting#01* type using the *classification* entity, as shown in Fig. 9. If *Fitting#01_AF1_0011* individual part is damaged and is replaced with

Fitting#01_AF1_0012 individual part, *Fitting#01_AF1_0012* becomes a member of *Fitting#01* type.

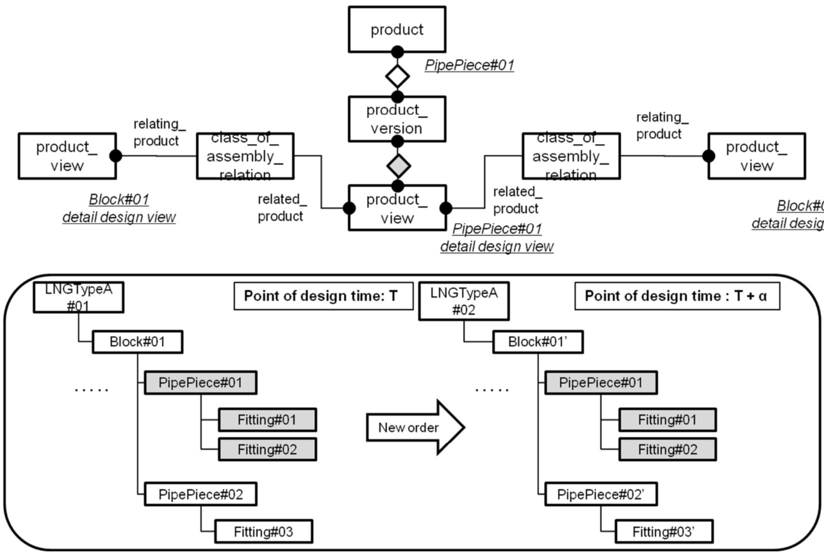

Fig. 8. Multiple references of a part – use of product structures of series ships

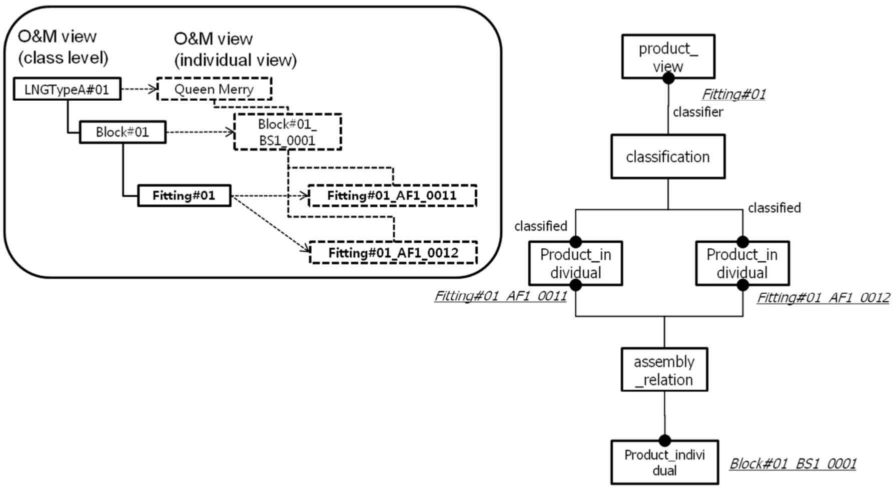

Fig. 9. Connection of class-level and individual-level product structures

Individuals exist uniquely in the time-space and do not change. However, role, usage, or classification of an individual at a particular period of time can be changed. For example, when *#1234* impeller is installed in *#5678* pump from the point in time *a* to *b*, as shown in Fig. 10, the assembly relationship between the two individuals only exists for that time period. After that time period, *#1234* impeller would be replaced with another part, repaired, or recycled. *#1234* impeller for that time period has the additional characteristic (the assembly relationship), hence, *#1234* impeller for that time period should be distinguished from *#1234* impeller for the entire life time. To this end, *#1234* impeller that exists from point in time *a* to *b* is identified as *#9012* impeller and *#9012* impeller is declared as temporal part of *#1234* impeller using the *temporal_whole_part* entity, as shown in Fig. 10. The assembly relationship therefore exists between *#9012* impeller and *#5678* pump.

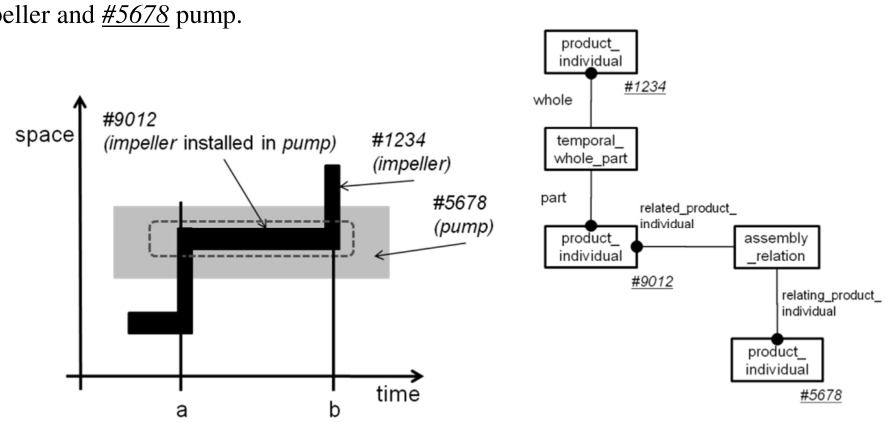

Fig. 10. Representation of usage history of an individual part

5 Conclusion

To use PLM technology as a solution to urgent problems of sustainable manufacturing, response to environmental regulations, and total lifecycle cost reduction, PLM systems need to support both individual- and class-level product structures as well as coupling of them. For example, eco-friendliness of steel used for the manufacture of a product can be determined only after we know what kinds of manufacturing processes are applied for the production of this material, how this material is transported, or whether this material is recycled, as shown in Fig. 11. These activities involve the management of individual-level data in addition to class-level data, hence, information model of product structure should support two different levels of product structures.

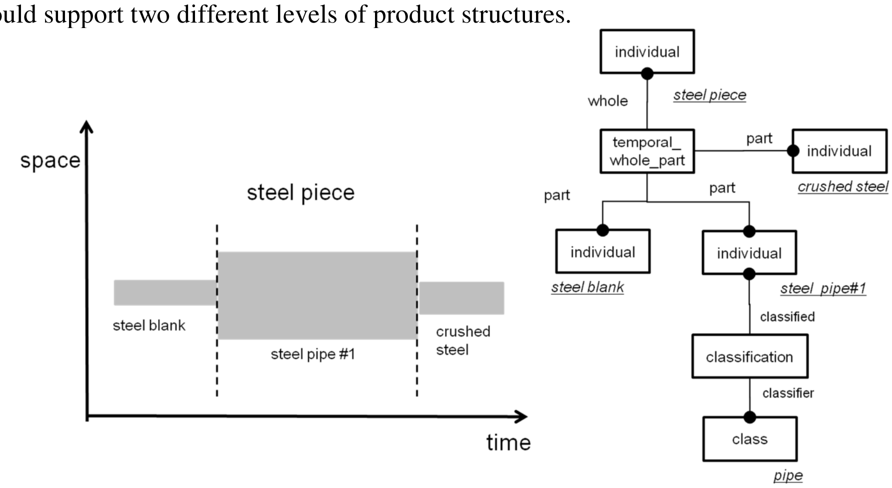

Fig. 11. History tracking of steel

Acknowledgment

This research was supported by Kyungpook National University Research Fund, 2010.

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PEGASE: a platform tool to help change management support during the implementation of a PLM system in an industrial company

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Abstract: PLM is an approach for product information management starting with the initial idea for the product and continuing through to the end of the product's life. PLM systems are the enabling technologies which support this approach. To date, efforts in this regard have focused on the development of industrial tools (CAD, CAM, PDM, PLM systems etc.) which have had a significant impact on user working methods. Analysis of PLM system practices has shown that one of the major problems in implementing them is not related to the technology itself, but instead to the difficulty experienced by the end user to adapt to such tools. Indeed, these tools necessitate many changes within the organization in terms of process, methods, etc. The way change is driven within an existing organization is therefore the key to implementation success. This is even more visible in SMEs. PEGASE is a platform which uses a new approach to enable change within the organization. This approach is based on a Serious Game architecture, the goal of which is to promote the added value of PLM systems within a company.

Keyword : PLM, Change Management, Business Process, Serious Game

1 Introduction

To maintain their competitive position, industrial companies must improve customer satisfaction, enhance their productivity and permanently create innovative new products in a shorter time to respond to customer demand. To achieve these objectives, companies need to be proficient in several areas: the optimization of organizations [2], control of industrial processes, better management of data and product information. There is also a need to develop a learning organization so that every employee, every team, and eventually the entire company can maximize their potential.

In this context, the information system plays a crucial role. It encourages innovation by giving employees access to tools enabling them to work more efficiently. For industrial enterprises, the information system managing the product lifecycle (PLM - Product Lifecycle Management) responds to this demand by capturing the technical heritage and making the right information available to employees.

However, the implementation of such a system usually leads to many changes within user practices.

This paper aims to propose an approach to simplify change management during the implementation of a PLM system. Firstly, we review the fundamentals of driving change and their involvement in the specific context of the implementation of a PLM system. Secondly, we present the PEGASE Serious Game, a tool to facilitate change management during the implementation of a PLM system. Thirdly, we present some initial actions in this platform game through the integration of real scenarios in industrial processes.

2 PLM and change management

2.1 Change management

Change management is a set of processes employed to ensure that significant changes are implemented in an orderly, controlled and systematic fashion to effect organizational change. Change management facilitates acceptance by employees of the changes caused by the implementation of a new project. It reduces failures and encourages appropriation [16] of new procedures [8]. Approaches to managing change are generally based on following items:

- Participation: Involve users in the project from an early stage, in particular to take into account their views and ensure that the final product meets their expectations;
- Communication: Establish and maintain communication throughout the project, thereby enabling employees to understand and accept the changes to come and to be kept informed of the project's progress;
- Training: Ensure that users have acquired the necessary knowledge.

According to Martin [19], change can be seen as a curve including the following steps: doubt, current situation, trigger, project, action plan.

According to Prochaska and Velicier [18], change is a process operating in cycles, with each cycle comprised of six stages of behavioural change: the pre-intention, intent, preparation, action, maintenance, resolution.

The effectiveness of the implementation of change depends on the quality of the learning process [1] introduced at both individual and team level, as well as on the interaction of both.

As such, during the change management process, we identify driving and inhibition forces which compete against each other. To be able to drive change by powering the driving forces for the conduct of the project whilst cancelling inhibition forces (restraining forces) or resistance [12], it is essential to have a good knowledge of risk factors and of what causes the resistance to change. The change induces an environmental change of the individual. This can cause anxiety. In terms of community causes we consider we consider that employees of an organization share common values, corporate culture and social gains that may be reduced by changing the company organization. Structural and cyclical causes are located in the corporate culture, such as working conditions (hours, routine, etc.), and the functional organization of the company (office structure, organizational hierarchy, etc.).

Finally, resistance to change is significant. Too often the weight given to the implementation of the technical objective (the software) is disproportionate compared to the effort used in deploying the methodologies of change management when available.

2.2 Impacts of PLM implementation

PLM systems affect the organization's business practices. Changing the organization creates difficulties in working, regardless of any technological problems

The results of a study [10] show that there are either difficulties or rejection in 45% of cases where PLM systems have been implemented. The causes of these difficulties are diverse (system failures, poor ergonomics etc.) but often result from employees' reluctance to use the system. The survey concludes that change management needs to be organized in order to reduce the number of failures.

Finally, we note that such problems are the main symptoms of a lack of change management. Regardless of the actions of general change management, we offer three more specific and more relevant actions within the context of deploying a PLM system.

Working on communication. Communication is paramount to the success of the project in order to bring the teams together. To do this, a company should implement the following actions:

- Highlight the interests of such a system without minimizing the constraints;
- Inform everyone within the company of the project and its progress and status through simple actions (newsletter, demo, participation in fairs, etc.);
- Clearly define the project's objectives in the short and medium term (which parts of the company will be affected, under what terms, stages of deployment, etc.).

Implement a participatory approach in order to enable users to capture a tool with a better response to their needs:

- involve staff in the choices and system configuration (importance of user references);
- in order to enable them to fully capture the tool, a training phase is also essential.

Stimulate the responsiveness of the project team in order to identify bottlenecks and suggest corrective actions at the earliest possible stage.

All of these elements will help organize change management within the company. Under the project, only a certain number of points can be addressed within the context of a Serious Game.

3 Approach to change management by the Serious Game

The implementation of a PLM system significantly alters the organization of the company, particularly in the context of SMEs. Resistance to change (individual and collective) appears naturally during the start-up of this type of system [6] [7]. Our approach is to propose an innovative approach to facilitate this change through Serious Games. The Serious Games are educational learning software conveying a message through the fun of video games.

The PEGASE project (Serious Game Platform Backing and monitoring of change in SMEs / SMIs) defines an environment of support for change management in industrial enterprises with an approach around the Serious Games. The purpose of this project is to develop a real Serious Game platform to help companies to effectively support their staff in adapting to the changes brought about by redesigning their information systems. The challenge of the project lies in the ability to deliver rich content to companies with an attractive environment.

3.1 Description of PEGASE platform

The Serious Game covers areas such as education, defence, health and marketing. This project specifically addresses industry structures and small business users.

The general context of the project is change management in industrial enterprises. The two main areas of work are:

1. A learning environment which was developed within the SYSCOM team [4] [5];
2. A content management environment which was parameterized around the audros PLM (Product Lifecycle Management) system.

The following figure provides a synoptic view of the PEGASE platform. It maps two main components.

The success of policy change management depends on the company, its history, its industry and its approach. Approaches to change management and training often result in failure because they are not always adapted to the context. The relevance of the PEGASE project is twofold: the use of video game techniques which develop the attractiveness and adjust game settings to business contexts [13]. We therefore propose a platform with the following characteristics:

3.2 The implementation for the change management

The PEGASE project is a software platform subject to two important constraints:

- The scripting environment should provide appropriate uses of the company's activity [3] [9] [11] [13] (automotive suppliers, toy industry, watches) and company size (multi-player scenarios, collaborative, competitive).
- Evaluation of the use and ownership of content by a user [17] is needed in order to be able to provide qualitative and quantitative indicators on the effectiveness, attractiveness of this type of platform scenario for the implementation of renewed professional practices for the staff of the company.

The script involves a scenario model that defines the educational actions to be performed by the player. The achievement of these game actions (mission, quest, travel, speaking to a non-player, etc.) contribute to the implementation of action learning [15]. The model scenario is based on the work of Marty and Carron implemented in a previous platform [14].

Under PEGASE, modeled scenarios are complemented by an assessment of indicators. These indicators are intended to link a learning objective to a goal of completing a task or process content. The measurement of these objectives by indicators is possible by combining the system tracks on both the actions of players in the game and activities in the PLM system.

3.3 Scenario for change management

One of the main difficulties of this project is the definition of industrial scenarios. The aim of the modeled scenarios is to understand the value of PLM. The table below shows the main features we want valued.

Table 1 Classification of usage scenarios

Main category of scenario	Second category of scenario
Understand basic functionalities of PLM	
Understand and accept the consequence of PLM	Reduction of errors Access to information Information security
Understand the use of PLM as a tool for collaboration	Internal Collaboration External collaboration
Understand PLM to improve performance	Reduce the development cycle
Understand PLM to drive innovation	Knowledge reuse

In the design stage, this classification enables the trainer to build his scenario from a descriptive guide.

Initially, the proposed scenario is structured around a simple industrial process (purchase order) described in Figure 1. Without a PLM system, this process is achieved through traditional activities where the risk of error, as well as the tedious tasks involved, should be considered.

This process is carried out initially in the PEGASE Serious Game without any PLM system. The following figures describe the following actions:

- Discussion with colleagues and watching a training presentation (Figure 2)
- Collecting documents in order to complete and visualize the tasks in the process (Figure 3)
- Visualization of the order form, retrieval of information from the archives (Figure 4)

Once the process is carried out without a PLM system, a collective and individual balance of mistakes made by the player is presented. A mini training session on possible solutions to resolve their mistakes with the audros PLM system is then proposed. The process is therefore performed with a connection to audros.

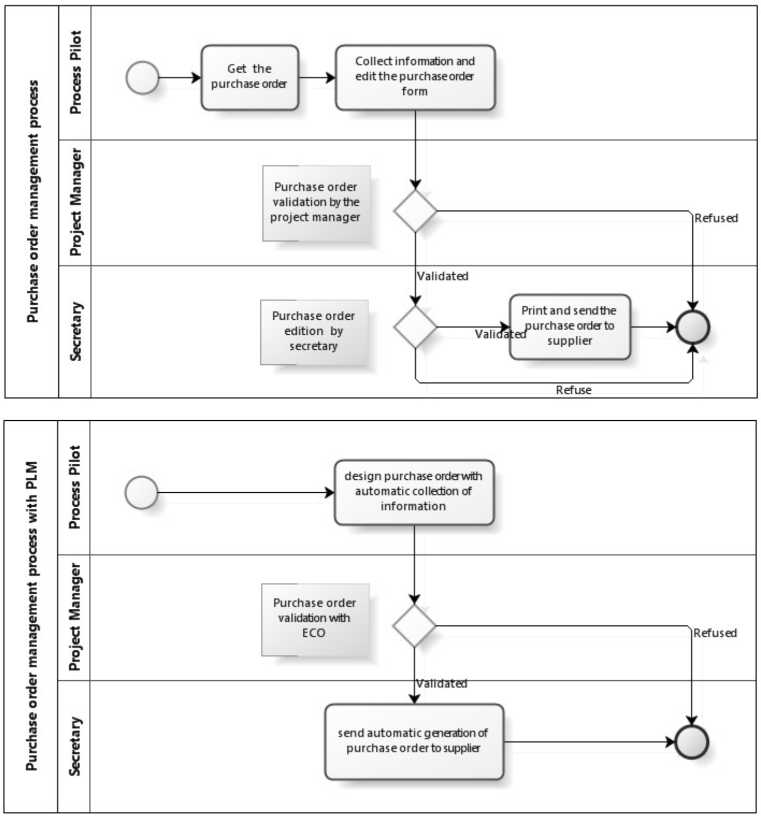

Figure 1 Purchase order management process with and without PLM

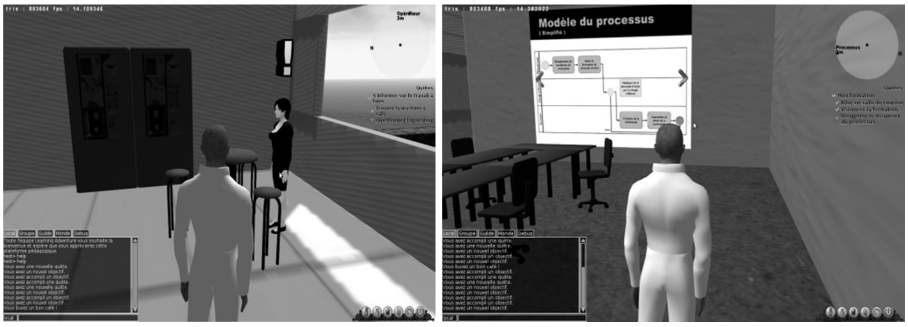

Figure 2 Screen shot PEGASE: interaction with other player

Figure 3 Screen shot PEGASE: player interacts with its environment

Figure 4 Screen shot PEGASE: player collects product data

The following figure shows a real-life experiment with engineering student. At the end of the game, players were asked to complete a questionnaire, and with this, we have assessed the level of acceptance change.

Figure 5 Experiment with engineering students

4 Conclusion

When implementing a PLM system within industrial companies, change management is not systematically taken into account.

Changes induced by PLM have a substantial effect on staff working methods. The PEGASE platform is a possible solution in order to facilitate awareness of the value of PLM and the acceptance of the constraints involved.

It is based on the attractiveness of a play action to deliver a message to the player of the game.

Thus, in the context of the implementation of a PLM system, the game's actions are aimed at discovering the benefits of such systems even when they necessitate new ways of working.

The first stage of the PEGASE project described in this article has enabled us to characterize the elements of relevance to a goal of change management. From these elements, we can define the structure of a model, linking usage scenarios and use of industrial processes based on the classification of targets. In addition to this binding mechanism, we established a classification system to construct scenarios based on clearly identified objectives. This is essential to us in order to subsequently define the indicators enabling evaluation of the achievement of these goals. The next step in our work is the definition of an indicator model consistent with models of the objectives defined in this article.

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Chapter 7
Knowledge Management

Traceability and project memory in PLM

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Abstract: The expertise represents an important capital in a company. The loss of this kind of knowledge has pushed the companies to look for a means to capitalize on it so as to use in the future. In fact, in many companies the design process usually learn from an old similar experience, the designers develop an existing solution, or try to take back old solution in order to adapt it to new requirements. This tendency to reuse old solutions is strengthened by constraints of time, of efficiency and of search of better reliability. Therefore, the importance of the capitalization of design project knowledge is more and more increasing. This paper presents techniques to extract and to represent this type of knowledge in a project memory, using Process Life cycle Management (PLM) platforms.

Keyword: Knowledge Engineering, Knowledge Management, Project memory, Traceability

1 Introduction

In a reuse situation, one of the most important designers need is to understand the choices made in the last projects especially their design rationale [12]. The designers ask a number of questions regarding these design choices like: why such element is necessary, why such choice was preferred to such one, how such inconvenient connected to such solution was treated, what other choices have been explored, etc. All these relevant questions represent the keys of the project memory comprehension and reuse. Therefore, the project memory definition has to give to the re-user the possibility to interpret the issues, the choices and the decisions; it has also to represent emergent knowledge during the project realization [15].

In order to favor the reuse, we have to help designers access to the context of the project carried out in the past. We have to construct project memories different from a simple archiving of only solutions in each project but also the reasons bringing to these solutions. These reasons have to show experts skills, representation of treated problems, the decision context, etc.

Otherwise, Knowledge Engineering [1], [7] offers a rational framework allowing a representation of knowledge obtained through the experiments. This technique found a great application in knowledge management and especially to capitalize knowledge [8]. In fact, the rational representation of knowledge allows their exploitation and their re-use. It is a necessary condition to allow a re-use and a knowledge appropriation. Behavior laws provide strong semantics to emphasize the reason of this behavior, ready to be reproduced to solve new problems [18]. These techniques provide semantic representation of knowledge that can answer to the main objectives of knowledge management: knowledge externalization and internalization [19]. For that, some knowledge management approaches aim at making explicit the problem solving process in an organization. Their techniques are inherited mainly from knowledge engineering. So, we find in these approaches in one hand, models representing tasks, manipulated concepts and problem solving strategies, and in the other hand, methods to extract and represent knowledge. We note for instance MASK [11], [16] and REX [13] methods. These methods are used mainly to extract expertise knowledge and allow defining profession memories. But knowledge in profession memory is different from which will be handled in a project memory:

1. The nature of knowledge is different. In fact knowledge capitalized with knowledge engineering approaches is related to experience. This experience is built along activities of an expert in which a lot of experiments are analyzed and structured by the expert; whereas knowledge produced in a project constitute one experiment to be structured. The profession memory contains knowledge from a field. Project memory has to deal with several fields. In fact, several teams (of several companies) and in several disciplines collaborate to carry out a project. So there is a collective and organizational dimension to consider in a project memory which is not considered in profession memory. Profession memory develops knowledge about problem solving in a domain [4] whereas project memory emphasizes knowledge about organization, negotiation and cooperative decision making in a project.
2. Capturing of knowledge is different. The realization of a project in a company implies several actors, if not also other groups and companies. For example, in concurrent engineering, several teams of several companies and in several disciplines collaborate to carry out a project of design. The several teams are regarded as Co-partners who share the decision-making during the realization of the project. This type of organization is in general dissolved at the end of the project [15]. In this type of organization, the knowledge produced during the realization of the project has a collective dimension which is in general volatile. The documents produced in a project are not sufficient to keep track of this knowledge which even the head of project cannot explain. This dynamic character of knowledge is due to the cooperative problem solving where various ideas are confronted to build a solution. So extraction knowledge by interviewing experts or from documents is not sufficient to show different aspects of the projects and specially negotiation. Traceability and direct knowledge capturing are needed to extract knowledge from project organization.

We present in this paper a structure to represent a project memory, considering cooperative dimensions. A traceability and capitalization approach is then presented that help to capture design project knowledge using product Life cycle management tools.

2 PROJECT MEMORY

2.1 Definition

A project memory describes "the history of a project and the experience gained during the realization of a project" [15], [17]. It must consider mainly:

- The project organization: different participants, their competences, their organization in sub-teams, the tasks which are assigned to each participant, etc.
- The reference frames (rules, methods, laws ...) used in the various stages of the project.
- The realization of the project: the potential problem solving, the evaluation of the solutions as well as the management of the incidents met.
- The decision making process: the negotiation strategy which guides the making of the decisions as well as the results of the decisions.

A number of methods such as QOC, DRCS, DIPA [8], etc. have defined frameworks to represent justifications and decision making. The main criteria emphasized in these frameworks are questions, propositions and justifications. These criteria help to represent negotiation and decision-making. These criteria emphasize negotiation characteristics and mutual influences whilst also being easily understood by organization actors. A project memory must contain elements of the experience coming both from the context and from the problem solving. Context is important to enhance learning in an organization 10 . There is a strong mutual influence between context and solutions. So that if the context is omitted the restitution of problems solving is insufficient. Except the system DRCS, design rationale approaches do not define techniques to represent this influence between the context and problems solving in a project. Even DRCS system can only allow representing a part of this context (the tasks organization and the projection of the decisions on the artifact). In the same way, we can observe some efforts in DIPA formalism to represent the organization of work in a workflow (task/role). However, other elements have to be identified such as constraints, directives, resources and competences, etc. We consider in our approach representing a more complete vision of the project context by emphasizing its influence on the problems solving.

We define first a project memory structure that allows representing the several concepts considered in project memory and their mutual influence.

2.2 Project memory Representing Structure

As we noted above, project memory has to consider from one side, several dimensions like: organization, problem context and definition, negotiation and cooperative decision making and from the other side, semantic and cognitive representation like: “know what” and “know how” 6 , 18 . In fact, to enhance learning lessons from projects , it is necessary to emphasize when and how activities are done and especially what and why of actions 10 .

We consider these two aspects in a structure to represent a project memory. The organization description (how and when) can be directly traced from design activity (Figure 1). We find this information in design environment and tools: documents, discussions, process, product, etc.

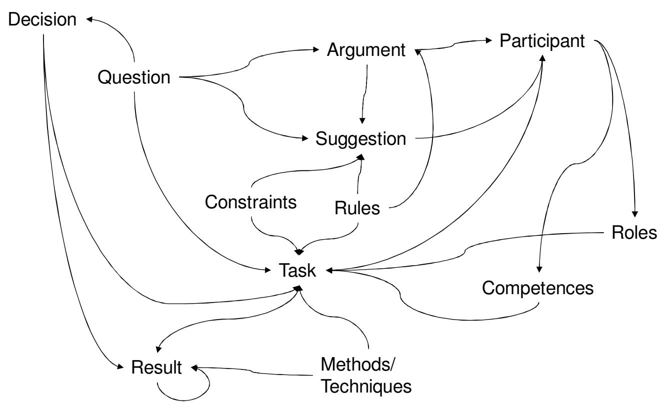

Figure 1. How activities are done in a project

Representing of the semantic aspect of project organization requires analysis and abstraction. So we use the relation between cooperative decision making and elements in project organizations in order to structure the project memory. This relation can be done mainly by emphasizing the characteristics of suggestions and decision, using criteria. We use the DYPKM approach 2 , 9 to extract criteria from decision making meetings and to define links between criteria and project elements. Examples of such links are shown in (2.2). These examples are extracted from a project that aims at proposing a number of principles that can guide companies to evaluate their risk in their activities 2 .

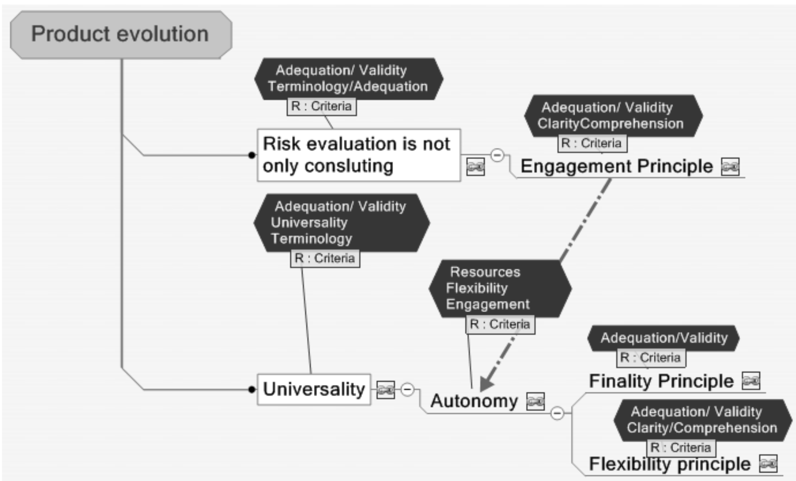

Figure 2. Links between criteria/decision and solution emphasize why of product evolution and the final solution.

That makes a first level of structuring the memory. We aim in future work at grouping and doing aggregation in order to extract project organizations types.

Traceability must be based on integrated tool and approach in an activity. We use Product Life cycle management tools (PLM) which are currently used by designers, in order to integrate our approach in designers' environment and keep track of a project memory. We describe in the following the principle of PLM and how we use it to build a project memory.

3 Design Project Traceability using PLM

A product Life cycle Management is defined as "a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life-integrating people, processes, business systems, and information. ». 5 . « PLM holds the promise of seamlessly integrating and making available all of the information produced throughout all phases of a product's life cycle to everyone in an organization, along with key suppliers and customers. ». **Fout! Verwijzingsbron niet gevonden.**. So, a PLM allows managing the product data along its life cycle process: specification, design and manufacturing.

As we noted above, project memory has to identify explicit links between the organization of the project, the collaborative decision making and the results. We show in this section how we aim at using Windchill, a commercial PLM platform developed by PTC[1], in order to keep track of a project. In this paper, we present how we aim at integrating project data traceability within Windchill.

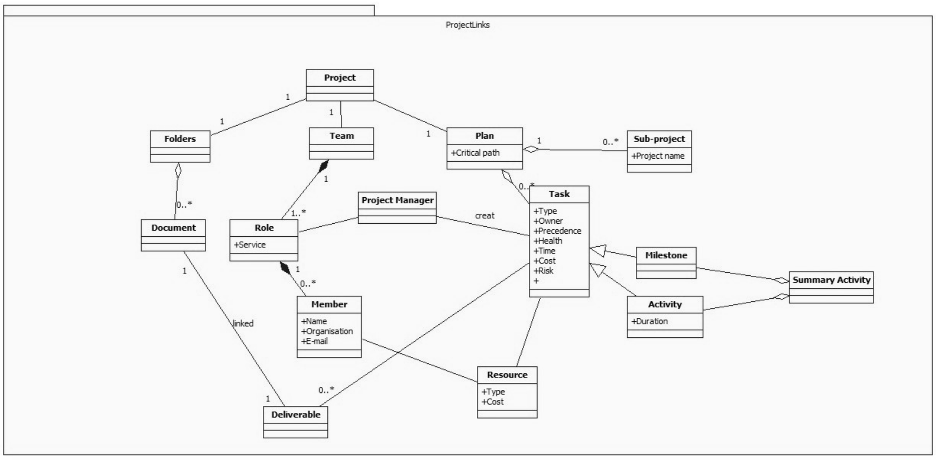

Figure 3. The organization of a project in Windchill

[1] http://www.ptc.com/products/windchill/

3.1 The organizations of elements in Windchill

There are a number of functions that support design project in Windchill. This organization links project to team, to documents and to process planning (Figure 3)

We can distinguish that some concepts needed in project memory are already represented in Windchill:

- The project team: members (their organization and contact), their role.
- The project process: planning, tasks, resources, milestones.
- Results: deliverables and documents representing the different parts of the product and in different views (geometric, functions, etc.).

There are also links between these classes:

- Task, members, roles and deliverables.
- Deliverables and intermediate documents.

There is also a traceability of evolution of the project:

- The changes of objects: versioning, forums, workflow, and meetings reports.
- The evolution of the product during process: concept, architecture, prototype, series.

The product development can therefore be represented as a decomposition of objects. Each object is described by its parts (components), description documents (specifications, propositions, etc.) and dynamic documents (CAD, etc.). Each part is considered as an object and be described by parts, documents and dynamic documents. For each problem related to a part, a problem report (if needed) is defined by the designer. A Modification workflow is then generated corresponding to the problem report (**Fout! Verwijzingsbron niet gevonden.**). This workflow is decomposed by decision making and modification phases. The impact of the problem is calculated and related project members are asked to decide about the modifications considering its impact. Decision making can be done by meeting and/or using a vote system. When the decision is made, modifications are performed on the part.

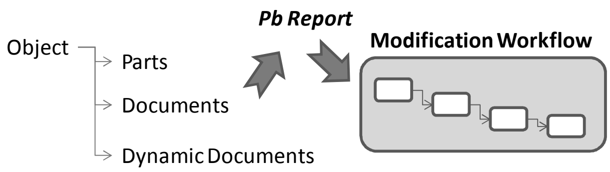

Figure 4. The description of the product in Windchill

3.2 Project Memory with Windchill

Handling a project memory necessitates to type the evolution of the project. We propose in our work to use decision making process and especially criteria of negotiation in order to annotate the evolution of a project (Cf. Section **Fout! Verwijzingsbron niet gevonden.**). As a first step we propose to use the product evolution and modification workflow in order to keep a structured track of this evolution. So, we change the modification report in order to emphasize the characteristic of asked modification in decision report. Summary of general problems in product design can guide the definition of this decision characteristic (Figure 5).

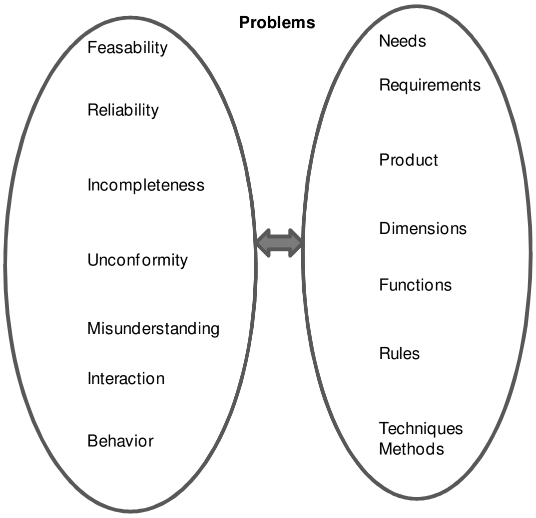

Figure 5. Criteria extracted from a classification of design problem 15 .

So designer can annotate each change by its characteristics and can obtain what is relevant in this evolution (**Fout! Verwijzingsbron niet gevonden.**). In fact, when a problem generates a modification workflow, we have an access to members that will contribute to the decision. The decision is represented in a report. This report must be described in a structured way: The problem, decision and relevant criteria and members who vote this decision. In the report we can also obtain a structured track of the discussions (arguments/criteria/ Members, propositions/criteria/Members). Designer who define the report have to use dedicated software for this aim. Textual report can be easily generated from this software if needed. So we obtain a link between the characteristics of the modification (criteria) the members who vote this modification and the result of this modification.

We aim also at using record materials like smartphone (iphone, ipad, etc.) in order to record meetings in a structured way. In fact, problems and members can be as input to prepare a meeting and the secretary has only to record discussions related to members and problem. We are developing this application with Canergy Melon University.

Figure 6 shows an example of the integration of criteria in the design cycle of a “PHILIPS Camera” using Windchill: specifications of the front of the camera: bottoms, display, etc. This characteristics annotation gives a first structuring of the product evolution. Based on that and using links between project elements, we can extract several views about the design of the product. For example, the reason of a result based on the project organization: members’ profile and roles and tasks, why such result for this requirement, etc.

We are working at changing the modification workflow and defining a research engine emphasizing the reason of the product.

As we can note, our proposition is mainly on the product evolution, but the project knowledge concerns also the organization of a project and not only the results. In Windchill, there is no representation of the evolution of tasks. In fact, tasks are represented in a planning and linked to members and objects. But the evolution of the planning is not enhanced in Windchill. In order to respect our project memory structure, we plan some changing in the PLM in order to handle a similat evolution of the project than the one concerning the product. In the same way, we have to keep a structured track of this evolution. So, as we proposed a structuring of the product using characteristics, criteria will be also used to characterize decisions on tasks and project members.

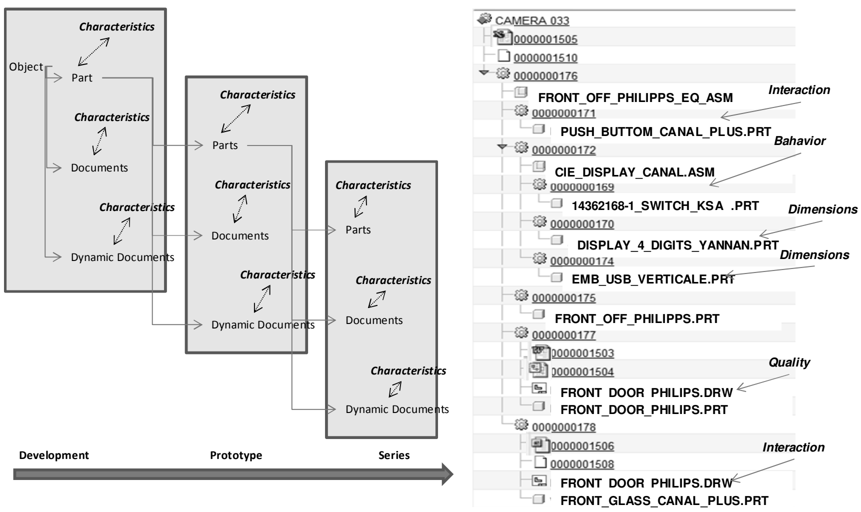

Figure 6. The characteristics annotation of the product evolution and an example

4 Conclusion

The main objective of knowledge management is to enhance learning from experience in order to promote innovation. Learning cannot be well done if the objectives of procedure and knowledge are not shown. The “why” of an activity is important to enhance the development of strategies by the learner.

Otherwise, presenting only concepts without examples is a lack for learning. So, examples which illustrate conceptual strategies and models have to be presented in order to give concrete aspects of strategies. Examples are important especially when we present in a memory a cooperative activity where different views and fields are involved.

We present in this paper a structure of a project memory which considers from one side the cooperative dimensions (organizations and negotiation) and from another side the semantic aspect (characterization of information).

To keep track of this memory, we try to integrate some changes in a Product Life Cycle Management platform. We study first how the commercial PLM platform Windchill supports project management and then how to use it to keep track of design project knowledge.

Within the Windchill platform, the evolution of the product is represented but there is no representation of the evolution of the project organization (task and participants). We propose to use customized workflow and customized report models in order to characterise the evolution of the product and represent a first structuring of knowledge. We aim at using links and changing planning in order to also characterize the evolution of the project organization.

We plan at developing links and using search engine in order to handle design project memory and promote learning from past design projects. We study also techniques to structure coordination exchanges based on pragma-linguistics analysis [14].

Finally, having a lot of applications of the project memory can help us to study results and build some aggregation and classification in order to distinguish generic cooperative strategies 9 .

Acknowledgment

We thank The Champagne-Ardennes Region and FEDER, sponsors of this work.

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A PLM/KMS integration for Sustainable Reverse Logistics

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Abstract: The international competitive market causes the increasing of shorten product life cycle and product development process with the improvement in term of time, cost and quality while increasing the waste generation. To reduce the waste generation, companies follow the environmental legislation and focus more and more on the product lifecycle sustainability. Sustainability on product lifecycle encourages in reducing wastes, saving resources and energy, reusing product and its component and avoiding of usage hazardous substances as well. Therefore, this research work is aimed to establish a Knowledge Management System (KMS) based on a multi-agent system in order to manage sustainability knowledge related to environmental security and performance through the link between Agents' knowledge base and Product Lifecycle Management (PLM) system. It will help the decision makers in each stage of the lifecycle and make them take into account the environmental impacts of their decisions. The proposed architecture will be illustrated on an industrial case study.

Keyword: Reverse logistics, Product lifecycle sustainability, Multi-Agents System, Knowledge management, Decision making

1 INTRODUCTION

In present business competitive, time is valuable; the quicker products are introduced into the market, the more the profits are for the organization. The Product Lifecycle Management (PLM) is a key solution to manage information and product knowledge; it utilizes the advantage of information sharing to decrease timeline for product development and production process, in order to accelerate the speed to market. Because of that, since few years, a huge amount of products have been introduced into the market. So, what will happen to the environment when these products will reach to their end-of-life? If these products are dump into environment, our environment will be affected unavoidable.

The degree of environmental impacts is determined by materials and energy used in the products and in the production processes, including the outputs generated at all stages of product's lifecycle. For example, components of electronic products could contain several hazardous materials (e.g. mercury, lead, cadmium, etc.) which are dangerous for human health and environment. The higher is the number of products introduced into the market, the more waste of products are generated. So, environmental regulations and legislations have been established in order to require the organizations to take responsibility of their products when they come to end-of-life or end-of-usage, to limit and control waste generations and to dispose them in a proper manner.

Taking into account the sustainability, customers are increasing their purchasing decisions on environmental impacts generated from products, or buying products made of recycling materials. These challenges make many companies pay attention on reverse logistics as a key strategy to handling and disposition of product returned from customer. Reverse logistics is a process to recycle resources or deal with the waste materials, with a reason cost, from consumer to production point [1]. Managing the returned product efficiently not only reduces the amount of waste generation but also encourages the company in the design processes to avoid the use of hazardous substances in products.

Besides, in order to produce the products that are sustainable and less harmful to environment, rules, regulations and knowledge related to all activities of organization, together with environmental performance which occurred during the production process and the recovery process, should be captured, evaluated and stored for further useful. Considering environmental issues and regulation can help users on their decision making during the design, the production and particularly the recovery process. Consequently, it will help organization, on not only, minimizing their waste generation but also improving their environmental performances.

This research proposes to develop a Knowledge Management System (KMS) based on a Multi-Agent System (MAS) in order to manage the knowledge related to environmental regulation. The proposed system will facilitate the efficient decision making by constructing the link between the Agent's knowledge concerning sustainability and the PLM system. With this architecture, the environmental impacts will be considered in each stage of the decision making process and for the whole lifecycle of the product.

2 LITERATURE REVIEW

In the past, although organizations have been developed a better quality of products continuously, the environmental effects still have been ignored during the product development. The products end-of-life and their substances were discarded in the inappropriate ways which could damage to the environment.

Now, by concerning to environmental impacts, organizations are increasing the improvement to satisfy customer requirements through sustainability of their product by using efficiently of raw materials. To success of using raw materials efficiently, organizations should reuse components and materials from the returned product which will result in reducing costs of production and waste generation [2]. Then, the organization can create their profitability from the returned product [3]. Accordingly, reverse logistics are increasingly utilized as a competitive advantage of organization in managing the returned products [4].

The purpose of a reverse logistics process is to make benefits from the value of returned materials or to find the proper way to dispose returned product [5]. Many researchers have classified reverse logistics process in different ways. De Brito and

Dekker [6] have separated reverse logistics processes into 4 processes: Collection, Inspection/ sorting, Re-processing or direct recovery and Redistribution while Thierry et al. [7] demonstrated their options on product recovery into repair, refurbishing, remanufacturing, cannibalization and recycling. All these options of recovery processes in reverse logistics mainly concern in a way to effect to environmental and economic efficiency.

Since the environmental protection is more concerned, knowledge about environmental regulations such WEEE [8], RoHS [9], Battery directive [10] and other environmental legislations should be taken into account and shared by all users in the PLM process in order to support users making their decisions properly. These regulations guide the organizations in reducing the consumption of non-renewable resources, decreasing the amount of waste materials generation and towards the sustainability at the end.

The environmental regulations and policies from governments encourage organizations to innovate and develop their product in term of sustainability. Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) is one approach of integrating the environmental issues for a new product development in the process of design, material selection, and manufacturing and managing end-of-life product [11].

For examples, (1) Cisco introduced a take back and recycling program to collect and dispose their end-of-life product. This program complies with the EU WEEE directive. With this program, Cisco helps reducing the impacts on the environment through recycling, reusing and the properly disposing of its end-of-life product [12]. (2) Hewlett-Packard [13] has designed their products, e.g. printer and laptop, to be friendly with the environment by reducing energy used in production process and during product life span, reducing the use of hazardous materials and designing products that are recyclability.

Managing the returned product has faced on how to use technologies to develop information system to deal with the returned product. The new technologies have been used for information sharing in the chain logistics such as the agent-based technology [14, and 15], RFID technology [16, and 17] or web services [18, 19]. Although, some of these technologies are applied on the return product management [20, 21], they still have a limitation.

Due to the lacking of information sharing on environmental regulations and performance between users in product lifecycle management, in the next section, we will propose a knowledge management architecture, which is based on a multi-agent system, to manage the knowledge related to environmental performance. This system will make the link between agent's knowledge base and the PLM information system and support users in their decision making, considering the environmental impacts from their products.

3 KNOWLEDGE MANAGEMENT ARCHITECTURE

The developing of a knowledge management system is intended to support users sharing and communicating all information related to product and also related to the environmental regulations and performance. Figure1 is the description of the conceptual model of the proposed architecture.

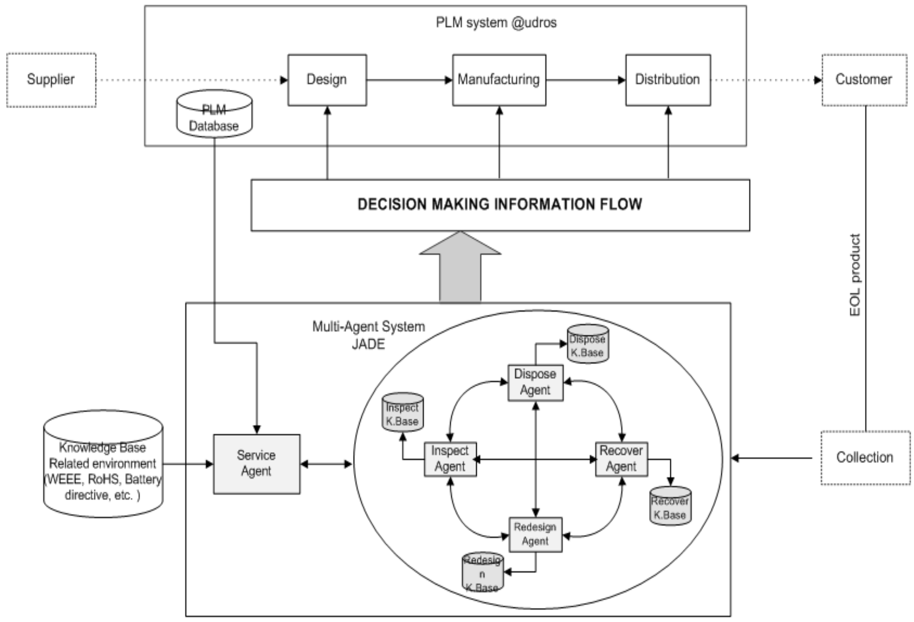

Figure 1 The proposed KMS/Multi-Agent architecture

The multi-agent system is connected to the PLM database where the product information is stored. It is also connected to the environmental knowledge base. This environmental knowledge base is shared by the agents and also by the users in each stage of the PLM process. Each agent has its own knowledge base which contains the knowledge related to environmental impacts and performance. In the following section, we describe this Multi-Agent System/

3.1 The Multi-Agent System

The proposed multi-agent system includes five agents: Service agent, Inspect Agent, Recover agent, Dispose agent and Redesign agent. Each agent works independently from the others. However, they communicate and interact to share knowledge and information. Each agent communicates with the others through Agent Communication Language (ACL) which is complied with FIPA specification (The Foundation for Intelligent Physical Agents) [22]. ACL is a language, which provides agents with a means of exchanging information and knowledge and defines the types of messages.

The role and the decision making process of each agent is described briefly in the following section:

***Service agent*:** This agent handles tasks and provides information (extract from PLM database) when requested by other agents.

Inspect agent: Its role is to inspect the returned product using the information provided from Service agent, from its knowledge base. It communicates to other agents asking for supporting information during its inspection process.

Recover agent: The agent analyses and offers the solution on recovery the returned product and its components using its rule based and information from Service agent and environmental knowledge base.

Dispose agent: The agent offers solution in the process of recycling the returned product. The solution is derived from its rule-based and environmental knowledge base. This solution encourages users in stages of PLM reducing the hazardous waste which effect on human and health and environmental performance.

Redesign agent: There are rules of environmental knowledge base which concerns in the environmental performance. The solution derived from the agent will help user keep in mind the integration environmental constraint in the redesign/design process.

Figure2 presents the rule-base structure in knowledge base of each agent. The information related to the environmental performance of each agent will be extracted when agents execute their inference engine during their processes.

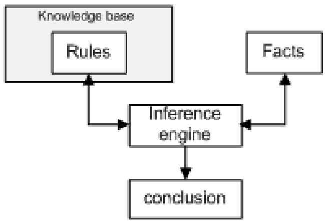

Figure 2 The structure of rule-base

We defined our system specifications by using AUML diagrams (Use case diagram, Activity diagram, class diagram and etc.) to describe the way of our agents communicate to each other during processes for their decision making.

Figure2 illustrates the communication between Service agent and other agents during the inspection process. The RequestToPerformTask() of Service agent is to send the message to agents depend on the status of the returned product. For example, if the status of the returned product is “register”, it means that the returned product is needed to inspect. To inspect the returned product, Inspect agent requests product information from PLM database, SendMessage(), by sending message to Service agent. After receiving information from Service agent and other agents, ExecutingEngine() will be executed to find the solution/destination of the returned product from its rule-based and environmental knowledge base. Then ConfirmTask() will be sent to Service agent to confirm that the inspection process is done.

Figure3 illustrates class diagram communicating between Service agent and Inspect agent during the inspection process.

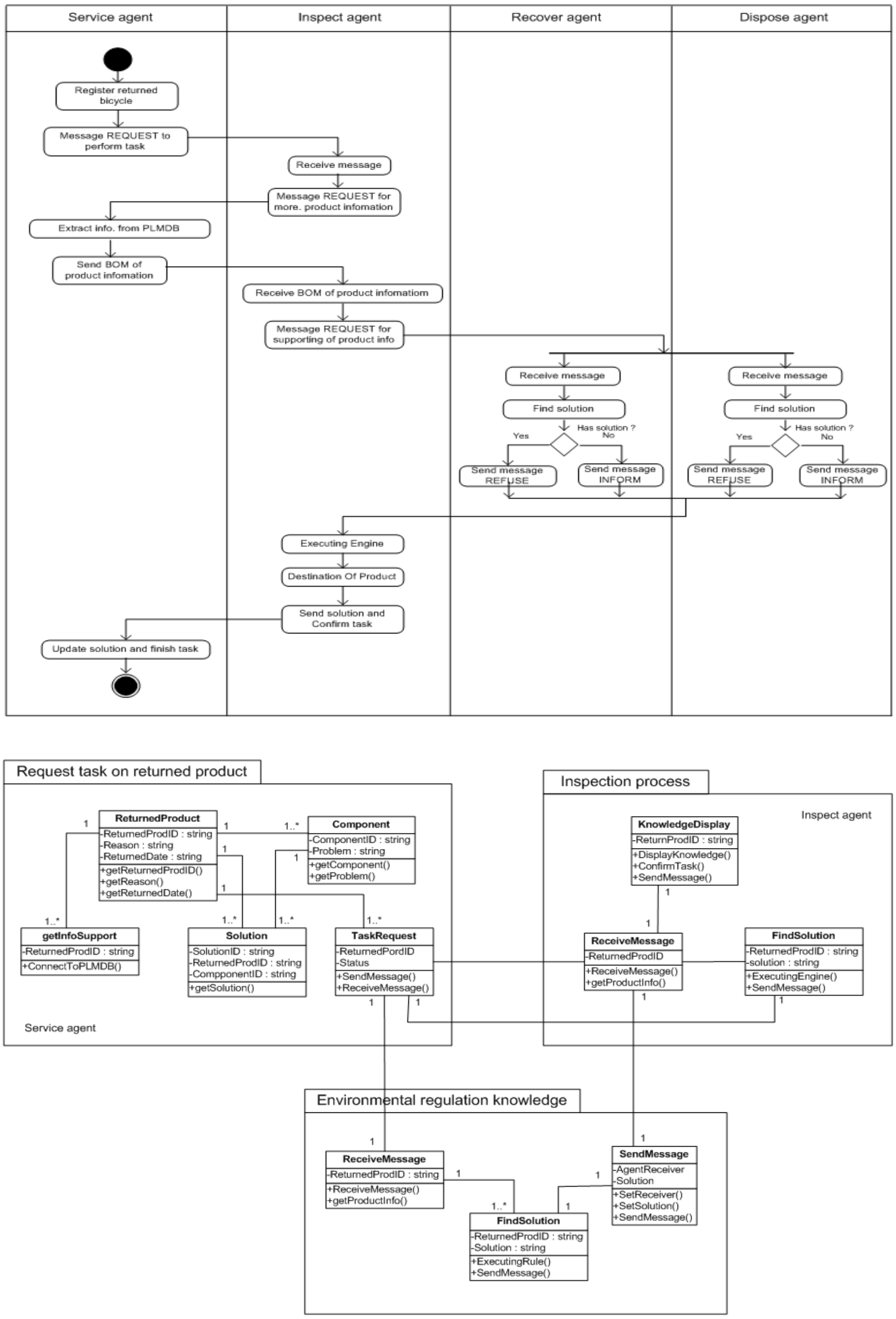

Figure 3 The interaction between *Inspect agent*, *Service Agent*, during inspection process

The prototype of this Multi-Agent architecture is in the process of development; it is based on the JADE (Java Agent Development Framework) platform [23]. JADE is an open source, implemented in java language and is in compliance with FIPA specification.

3.2 Knowledge representation and Decision Making Process

3.2.1 Rule-based reasoning

In the rule-based approach, the knowledge is represented as a set of "IF…THEN…" rules to represent the domain knowledge. The inference engine is a system which processes the rules, and the knowledge, based on the fact of the given situation. In this work on multi-agent system, we used a rule-based reasoning approach to formalize the environmental regulations. This in order to support users in their decision making process. Figure4 illustrates an example of environmental legislation of the European directive RoHS formalized using rule-based concepts [9].

Rule1:
IF product falls under category 3
THEN product is mobile phone
AND reference is WEEE directive Annex IB

Rule2:
IF component = printed circuit board AND printed circuit board contains lead
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for lead
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Rule3:
IF component = printed circuit board AND printed circuit board contains mercury
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for mercury
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Rule4:
IF component = printed circuit board AND printed circuit board contains hexavalent chromium
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for hexavalent chromium
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Rule5:
IF component = printed circuit board AND printed circuit board contains polybrominated biphenyls (PBB)
THEN The maximum concentration value of 0.1% by weight in homogeneous materials for polybrominated biphenyls (PBB)
AND reference is amending RoHS directive Art.(1), decision applying from 1 July 2006 Art. 2

Figure 4 An example of Rule-Based Knowledge representation for RoHS regulation

3.2.2 Previous Cases experience

The previous experiences including the solutions are stored in the database of all the agents. Each agent checks in its database for solutions to solve the problems that occurs. A solution in the agent's case base system will be first matched and then sent to user. User will decide whether the solution retrieved is applicable or not to its problem. Our system is developed to manage experts' knowledge by exploring the best practices. Figure5 shows an example of existing case problem which concerns a bicycle.

Problem description:
ProductID: Bike-01
ProblemArea: Frame
ProblemDesc1: Small cracked on Head tube
ProblemDesc2: Down tube bended like curve

Solution:
IF Head tube small cracked THEN Welding

IF Down tube bended like curve THEN Using tools to make it straighten

IF small cracked on Head tube AND Down tube bended like curve THEN
Fix can be done but not well functioning on the use

Output:
1.After welding, a short period of using and need more frequency checking
2.Fix cannot be done then replacing with the new one

Figure 5 Previous case problem of bicycle in the *inspect agent's* knowledge base

3.2.3 Ontology

To make agents understand each other, the agents must speak the same language and also have a common understanding on the semantic of the knowledge (ontology). So, the ontology is a part of the agent's knowledge base which describes what type of things agent is dealing with and how they are related to each other. We have defined our returned product ontology for sharing information and knowledge through agent communications. Figure6 illustrates an example of the end-of-life returned product ontology, which has been shared between agents in the proposed system.

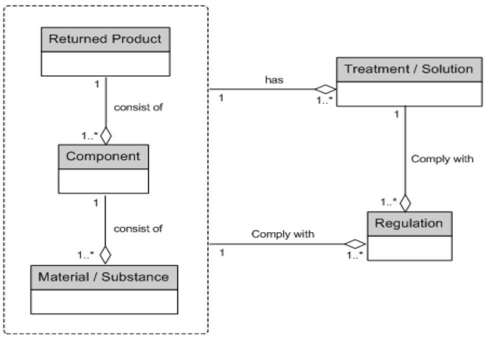

Figure 6 The concept of returned product ontology

4 VALIDATION OF THE SYSTEM : THE BICYCLE CASE STUDY

To validate the proposed architecture, we used an industrial case study about the lifecycle of a bicycle. According to our system, each of the returned bicycles will be inspected and checked by the *Inspect agent*. The *Inspect agent* receives the references information such as bicycle model (family), bill of material (BOM) or date of manufacturing from the *Service agent*. Then it analyzes the returned bicycle's problems through previous experience cases in its knowledge base. For example, a returned bicycle is returned with the reason "End-Of-Life", wheel and frame are broken and not functioning. The *Inspect agent* examines and checks its quality then analyzes and sets its destination to "recycling". Wheel, frame and battery are determined to discard (Figure7).

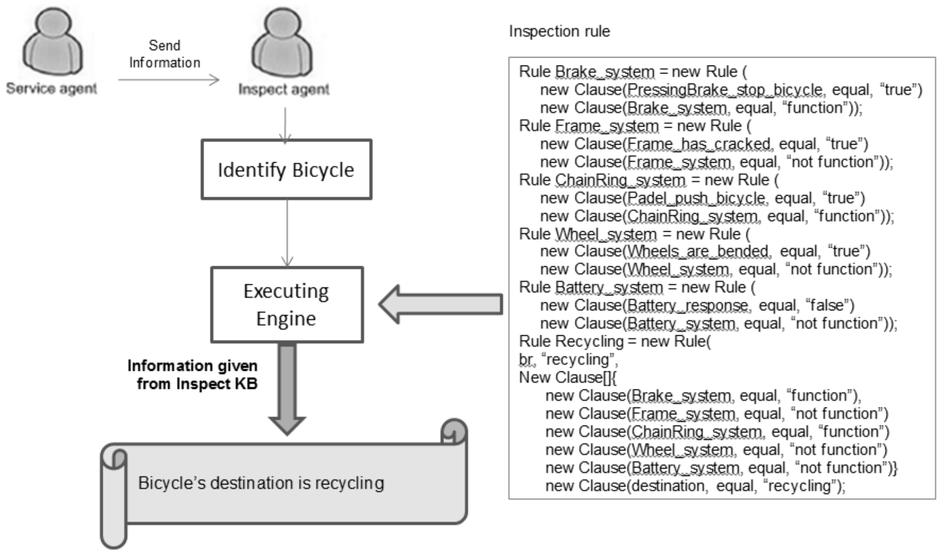

Figure 7 Executing inspection rule of *Inspect agent*

After that, the *Dispose agent* receives the message from the *Service agent* that there is a returned bicycle which needs to be recycled. It asks for some technical data such as: types of material of each component/part, number of components/parts… and sends messages to the agents about, for example, the disposal information of wheel, frame and battery.

The *Disposal agent*'s Knowledge base contains the rules or regulations on how to operate reusable, and non-reusable, substances/materials taking into account the improvement of the environmental performance. In our example, to recycle a lead-acid battery of bicycle that contains large amounts of lead. With the structure of rule-based of *Dispose agent,* it proposes solutions such as: the recommendation on how to discard lead-acid battery based on the information of the EU Battery directives. These solutions are significant information for the decision making of the users in order to save time and cost of operation process, as well as reduce the environmental impacts (see Figure8).

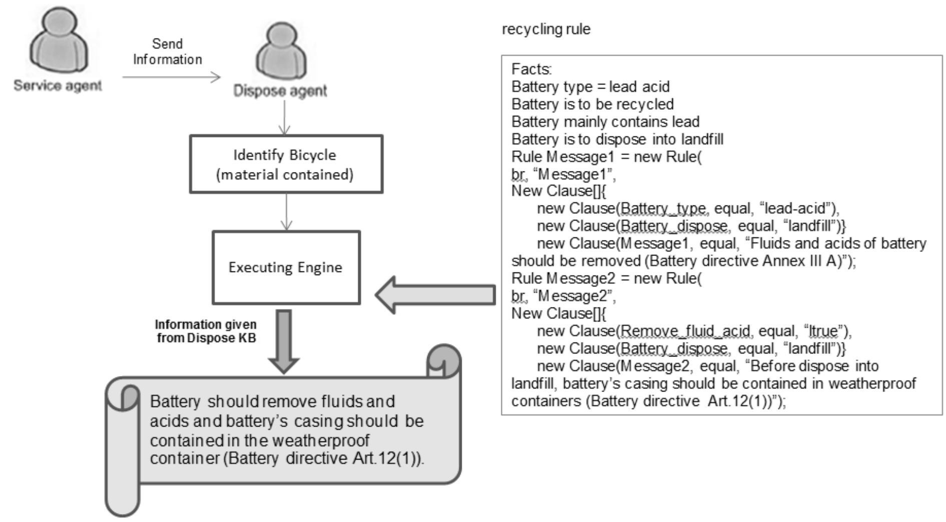

Figure 8 Message from Dispose agent after executing rule

In the case of returned bicycle to be redesigned, for example, a group of used bicycles returns to the organization having the same kind of problem: *customers did not understand how to use the shift gear when they were riding*, the *Dispose agent* will propose that the instruction guide should be reviewed to make sure that the customer clearly understand how to use the gear shifting efficiency. This solution will help in reducing the number of returned bicycle, and consequently, it will result the conservation of resources and energy and the reduction of waste generation; which improve the environmental performance.

5 CONCLUSION

A KMS/PLM architecture, based on a Multi-Agent system, has been proposed to share the product's knowledge and environmental legislations among reverse logistics activities. The environmental restrictions such as WEEE, RoHS and Battery directives encourage organizations to take responsibility by producing sustainable products. Sharing this environmental knowledge between users in every stages of product lifecycle process will improve the efficiency on managing of the end-of-life products in organization.

The proposed system will encourage organization on reducing the cost of waste disposal, increasing the reuse of materials/parts of product, helping user designing product and reusing efficiently materials and enhancing the environmental performance. We are now working on the ontology for the Environmental Knowledge base, and trying to validate the prototype on a real industrial case study.

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Progress with OntoCAD: A Standardised Ontological Annotation Approach to CAD Systems

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Abstract: As critical components of PLM systems, CAD/CAM systems have been actively developed for decades. There are, however, still research challenges confronting global competition and the ever changing market in the mechanical engineering domain. This includes collaboration within the internal enterprise and across enterprises externally, system integration, and knowledge representation and sharing across multiple engineering viewpoints. The OntoCAD approach has been proposed in previous work, in which multiple engineering viewpoints can be semantically represented, managed and further processed, assisting with system integration, knowledge sharing and reuse. This paper presents an extension of this research providing an update on the progress in two aspects. The first aspect is the exploration of a STEP-compliant anchoring mechanism for OntoCAD's semantic annotations to achieve compatibility between systems and maintain data integrity during data exchange. The second aspect is the application of cost estimation as a case study illustrating the representation of cost from an engineering viewpoint, and therefore supporting a costing application to validate the approach.

Keyword: annotation, ontology, CAD systems, collaboration, STEP.

1 Introduction

As a total system, product lifecycle management (PLM) [1] has been developed for decades to aid the processes of product management during the entire product lifecycle (PLC). However, there are many challenges still unsolved, including collaboration between participants within an enterprise or between enterprises, efficient data exchange while satisfying a query and maintaining data integrity, and more importantly issues of knowledge representation, sharing/reuse, knowledge processing, evolvability of the total system and so forth.

In this research reported in this paper, rather than covering every aspect of PLM systems, the computer-aided design (CAD) model as the basis for the creation and management of product data is the underpinning focus of the research activity. In previous research by the authors, a semantic annotation framework named OntoCAD [2] was introduced, which utilised annotation technology and three levels of ontologies as a kernel. OntoCAD is an extendible approach. Multiple engineering viewpoints (MEV) can be supported by OntoCAD and new engineering viewpoints (EV) can be readily incorporated into the existing system.

In this paper, an update on the progress of OntoCAD is reported, in particular two main aspects. One is an anchoring mechanism for semantic annotations that conforms to the International Standard ISO 10303, also known as STEP [3], the **ST**andard for the **E**xchange of **P**roduct model data. The second aspect illustrates the application of the OntoCAD approach through the use of a cost estimation case study to validate the proposed approach. In this work, cost estimation is represented as an EV, incorporated into the three-level OntoCAD ontology model, where the EV ontology is modelled through an adapted four-stage methodology. The success of integrating the cost engineering viewpoint shows that engineering viewpoints can be readily integrated into OntoCAD efficiently and without software modification.

In the next section, a brief introduction to previous work will be given. Detailed progress on the research to date will be described in section 3. This is then followed by experimental work based on a commercial costing software application SEER-DFM™ [4]. At the end, current research work will be discussed and conclusions presented.

2 Background and Literature Review

To cope with global competition and ever changing engineering markets, many technologies are under exploration or have become available. CAD systems, annotation, ontology and STEP are introduced in this section as the key computational enablers in the present work.

2.1 CAD Systems

As a result of the advances in computer science, much engineering design work is carried out using CAD systems [5]. With integration of other PLM components, CAD has been extended to cover more phases during the entire PLC rather than merely serving design, thus knowledge sharing and reuse by participants becomes more critical. To address this, semantic techniques and artificial intelligence (AI) technologies have become a major research direction of CAD systems [6]. Developments have included semantic approaches to simplify CAD models [7], system integration efforts [8-9], semantic description of design models [10] and many others.

2.2 Annotation

In general, annotation is additional information referring to a target object, e.g. a label attached to a geometry element in a CAD model. A generic annotation is composed of two components, an annotation anchor and annotation content. Many applications of annotation and related technologies are reviewed and classified in our previous work [11-12]. Annotations have been used ubiquitously to help people to remember, to think, to interpret and to share knowledge [13]. Especially in these latter two applications, the authors believe that semantic annotations can be used to clarify design intent and to share ideas between participants, for instances, to describe the purpose of through holes in a part within an assembly, or describing the functionality of a part.

2.3 Ontology

In the digital context, ontology is an advanced computational enabler that comprises a set of formal knowledge terms consisting of a vocabulary, mechanisms for semantic interconnections and rules of inference and logic to represent a concept of a physical or an abstract object. Ontologies are normally specified in a formal language and naturally contribute to knowledge storing, retrieval and reasoning. Among some available specification languages, the Web Ontology Language (OWL) [14] has been chosen for this research work, and Protégé [15] is used as a modelling tool.

2.4 STEP

Much effort has been contributed to establishing international standards for manufacturing data exchange, and the most widely supported standard, covering the entire PLC, is ISO 10303 (STEP), which is an international standard for the computer-interpretable representation and exchange of product data. STEP is adopted in this research project because it is widely accepted in industry, and many leading CAD systems are STEP compliant, such as NX [16] and CATIA [17].

2.5 Previous Work

Based on a comprehensive review of existing annotation approaches, classifying them in terms of usage, audience, storage location, representation, rendering system and so on [11-12], a general purpose semantic annotation approach called OntoCAD has been proposed by the authors as an aid to the development and customisation of CAD systems to support MEV [2], where the MEV refers to for example different design, manufacturing and analysis EVs. The concepts and interconnections representing an EV are specified using semantic annotations defined by ontologies. By using this approach, OntoCAD allows viewpoints to be readily extended or customised, and new viewpoints specialised to the needs of different knowledge domains or organisations to be developed and integrated in a plug-in manner.

As shown in Figure 1, the OntoCAD system comprises three modules: the OntoCAD interface module (OIM), the OntoCAD ontology module (OOM) and the OntoCAD MEV Agent (OMA). OIM is embedded in the CAD system interface, so that it interactively takes annotation as inputs from end users, therefore the annotations establish a knowledge base accumulatively. The captured annotation data is specified in OWL including both anchors and contents. On the other hand, OntoCAD ontologies work as a kernel that classifies knowledge into different EV, where each EV may overlap each other, i.e. some common concepts are shared in more than one viewpoint.

The OOM has a three-level ontological architecture, as shown in Figure 2. The top-level ontology previously was termed the MEV Agent ontology, but has been renamed the Foundation Ontology (FO) to reflect its incorporation of common knowledge, such as measurement units, data types, etc. The total responsibility of governing the overall status of OOM is the responsibility of the OMA module, which understands and processes user queries, and reasons over existing knowledge. In the middle level, EV ontologies (EVO) describe terms and relationships as engineering viewpoints in each corresponding domain. Finally, application ontologies (AO) build vocabularies for specific applications, so that the kernel can understand terms defined in any integrated application, and so that messages can be delivered and understood universally.

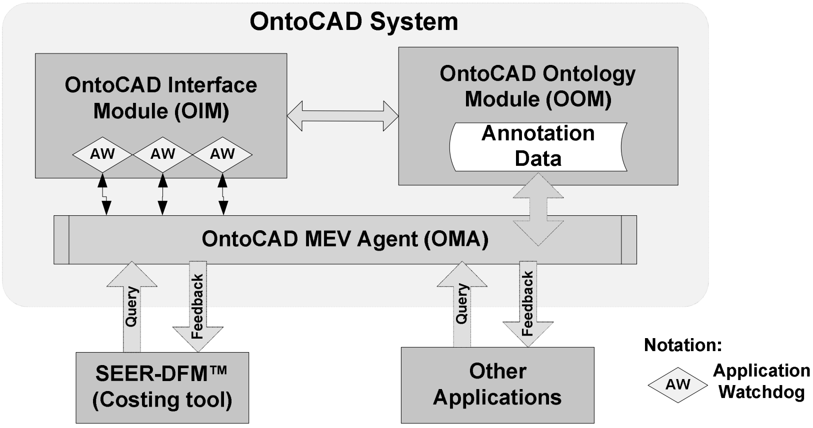

Figure 1 Overview of OntoCAD Approach [2]

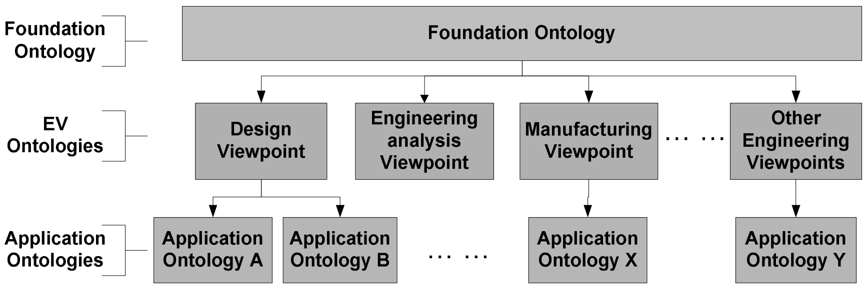

Figure 2 OntoCAD Multi-level Ontology Architecture (Updated) [2]

Having refactored the functionality of the OOM, the OMA is now responsible for all user queries and further intelligent actions, such as reasoning against existing knowledge. This sets clearer boundaries between the OOM and OMA, so that advanced query and reasoning mechanisms can be pursued in the near future without affecting the ontology.

This paper now reports on two aspects of recent work with OntoCAD. First is a standardised anchoring mechanism. Rather than using the authors' self-defined anchors, reported in previous papers [2], STEP standards are employed to represent geometries that are used as annotation anchors, in order to improve the ability of data exchange and interoperability across systems. The second aspect is an updated cost estimation EV ontology and SEER-DFM™ application ontology. This is to validate a general ontology modelling methodology and the feasibility and usability of the overall OntoCAD system.

3 Standardised Anchoring Mechanism

Interoperability in mechanical engineering environments is a major challenge, due to the fact that PLM systems contain sets of tools, in which each serves a different purpose and the data formats used by each tool are frequently different. This is especially true in the case of exchanging data across different CAD systems. This is why industry standards are needed in practice.

In previous experimental work, the API of a commercial CAD tool was used to attach semantic annotations to the geometry models created using the tool. The tool allowed this using an intrinsic annotation feature, but the annotation data was lost after exporting geometry definitions in external formats. In other words, the embedded annotation data is only maintained within tool itself. However, labels of geometry elements can be exported in STEP format and for this reason, STEP was chosen to allow consistent and exportable geometry labelling and thus export of annotations. In this section the extension of OntoCAD to incorporate a STEP-compliant mechanism for description of annotation anchors allowing OntoCAD annotations made in one CAD system to be exchanged with others is thus described. The approach may be combined with the authors' previous work on annotation of lightweight representations to allow such annotations to be fed back to full-featured CAD models [18].

There are mainly three types of information drawn from the STEP standard: data types, measurement units and geometry representation. All of these terms contribute to building the vocabularies and the interconnections between them in OntoCAD. Vocabularies defined by STEP help in modelling ontologies including top-level and EV ontologies, so that all participants use common terms explicitly, thus avoiding confusion.

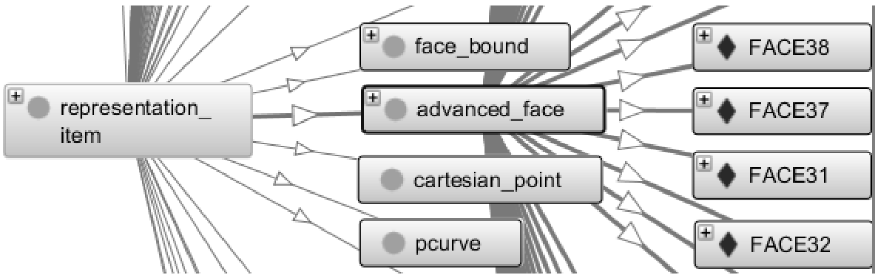

Figure 3 Partial View of Ontological STEP-Compliant anchors

Data types are extracted from ISO-10303-21:2002. They include integer, real, set, enumeration value, string, and binary and so on. Measurement units, including the international system of units (SI unit) (e.g. metre), derived units (e.g. millimetre) and suffixes (e.g. milli) are also extracted from this part. More importantly, geometry representation based on ISO 10303-11:1994 and ISO 10303-203:1994 ensures that all STEP-compliant systems interpret geometry in the same way. In previous work, general terms are defined for geometry representation, e.g. *face*. However these informal terms may not be understood by other applications. This is the main reason why a standardized anchoring mechanism is needed. In the same example, *advanced_face* is used instead of *face*. Moreover, semantics can be enriched by assigning *advanced_face* legal attributes including *label*, *face_bound* and *surface* according to STEP. Therefore, semantic geometry can be defined and any STEP-compliant application can understand geometries. In a nutshell, data types, measurement units and so forth are the elements of the foundation ontology backbone. Together with geometry representation items, their attributes and relationship rules, a skeleton is formed. Therefore a systematic anchoring mechanism can be built upon. Figure 3 gives a partial view of geometry representation items defined by STEP and the associated instantiated anchors (e.g. ‘FACE31’ and ‘FACE32’) in OntoCAD.

Some research effort has been dedicated to automatic transformation from STEP to ontologies in the literature, such as OntoSTEP [19] and EXPRESS-to-OWL-transformer [20]. However, automatic transformation is not the central work of this project. To ensure the accuracy and understanding of the ontology, manual transformation was implemented.

4 Case Study – Cost EV

A case study was carried out to validate the feasibility and usability of the proposed framework. The case study aimed to identify an appropriate ontology modelling methodology to establish and integrate a new EV ontology into the existing ontologies. In this case study, cost estimation is treated as an EV and the SEER-DFM™ software system as a costing tool to be integrated, so that cost related knowledge can be captured, stored, retrieved and exported to support SEER-DFM™ in order to get real-time cost results.

4.1 Ontology Modelling Methodology

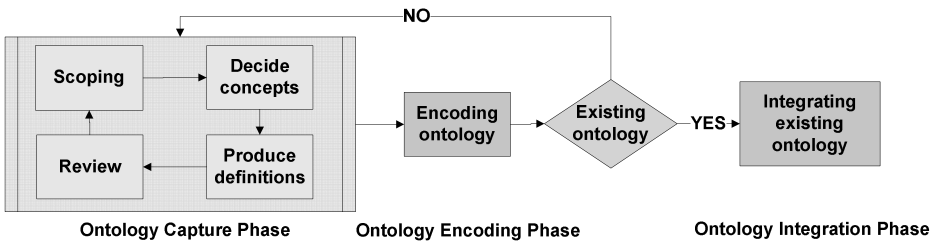

Figure 4 Procedure of building ontologies

To assist in establishing ontologies, some modelling methodologies are comprehensively reviewed by Corcho et al. [21]. Since a generic methodology is more appropriate to our research, the four-stage methodology introduced by Uschold and King [22] is adopted: identifying purpose, building the ontology, evaluation and documentation, where the second stage involves knowledge capture, knowledge encoding and integrating existing knowledge as illustrated in Figure 4. In the ontology capture phase, the Delphi method [23] was adapted to identify terms and thus to produce definitions in representing one engineering viewpoint ontology. The Delphi method aims to assist decision making by processing knowledge from a group of experts in an interactive and recursive way. We will return to this topic in section 4.2, where EV ontology modelling will be described.

More critically, two major tasks for this case study were completed at the stage of building the ontology: modelling the EV ontology and the application ontology, which are described in next sections.

4.2 Cost EV Ontology

The Delphi method was used to identify effective cost drivers in order to scope and conceptualize cost EV, where a cost driver refers to any factor that affects cost [24].

Based on a literature review, we designed a first round questionnaire with a list of candidate cost drivers that may potentially affect manufacturing cost and distributed this to a group of academic cost experts. For example, a list of candidates for the sand casting manufacturing process includes production quantity, direct labour hour rate, material, finished weight, tool description, inspection/rework, and so on.

Based on the feedback from the first round questionnaire, some common cost drivers were identified. Having validated against the commercial cost modelling tool SEER-DFM™, a second round questionnaire was produced in order to ask interviewees to identify the most significant cost drivers to concentrate on in the experimental work. In the second round feedback, cost drivers confirmed as the most significant factors included production quantity, material, finished weight, etc. in the case of sand casting.

Through this Delphi method, a set of cost drivers and basic cost rules were modelled as an EV ontology and incorporated into the existing OntoCAD ontologies. However, this ontology only covers a selection of manufacturing processes since completeness of this cost EV ontology is not the primary goal.

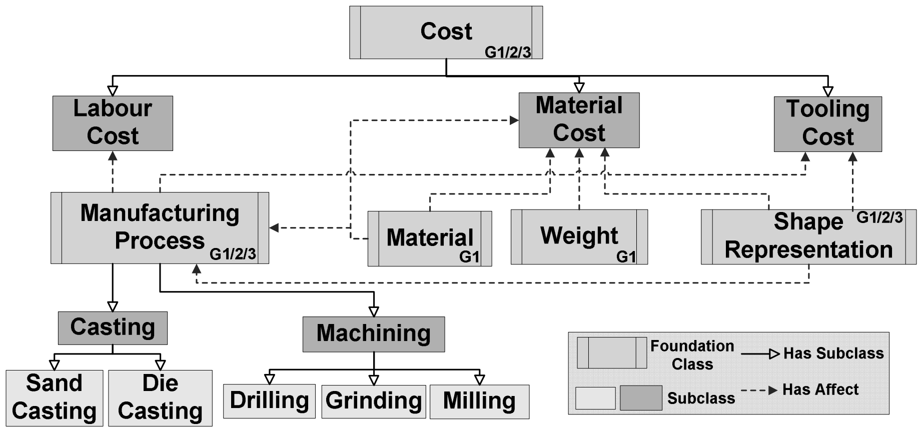

Figure 5 Partial View of Cost EV Ontology

In the cost ontology, as shown in Figure 5, costs are classified into three main categories: labour, material and tooling costs. Each is affected by a number of other foundation classes, for example, manufacturing processes have an affect on labour cost, as well as tooling cost, while material selection, part weight and shape representation affect material cost. For reasons of conciseness, not all ontology classes and interconnections are depicted in this diagram, neither are detailed relations between foundation classes and subclasses. For instance, there is a relationship between material density (material property) and part dimensions (shape representation), from which weight can be computed in order to evaluate material cost. This is under the scope of the foundation ontology, and is subject to granularity constraints G1, G2 and G3. G1 indicates that this class can associate with the highest level of geometry representation, namely a body, while G2 comprises face(s) and G3 elements include edge(s).

4.3 SEER-DFM™ Application Ontology

The actual task of cost estimation is achieved by passing the annotation data to the external package SEER-DFM™ to compute the cost results in terms of labour cost, material cost and other additional costs. In the experiment, the set of the most significant cost drivers was applied to the manufacture of a chosen passenger vehicle part design, which is a towbar manufactured using die casting, drilling, grinding and paint spraying as a finishing treatment. Data are passed to the external application by applying mappings between the FO, AO and EVO. This is illustrated in Table 1, showing the mappings appropriate to the example part.

Table 1 Definition Mapping for SEER Application Ontology

Ontology Level	**Corresponding Term**	**Definition in SEER AO**
FO	ManufacturingProcess	PRODUCT_DESCRIPTION_-_Process
FO	Material	PRODUCT_DESCRIPTION_-_Material
FO	Weight	PRODUCT_DESCRIPTION_-_Finished_Weight
FO	Quantity	ProductionQuantity
EVO	SandCasting (Manufacturing EVO)	Sand_Casting
EVO	DuctileCastIron (Manufacturing EVO)	Ductile_Cast_Irons; Iron_Cast_,_Ductile.
EVO	DirectHourlyLabourRate (Cost EVO)	PRODUCT_DESCRIPTION_-_Direct_Hourly_Labor_Rate

4.4 Validation And Documentation

Having modelled and integrated the EV and application ontologies with the existing ontologies, the approach was tested through the OntoCAD software developed earlier as a plug-in application to a commercial CAD system. The MEV agent can explicitly understand the queries made from SEER, which are satisfied with accurate annotation data retrieval and then fed back to SEER. The validation therefore succeeded, which shows the proposed ontological approach can be readily extended with new EV-level ontologies. The experiment also showed that the annotation system is evolvable, and that new EVs may be added to a CAD environment, including data checking and the preparation of data for external applications without knowledge of software programming or with much less programming effort.

In general, the modelling processes needed to be iteratively evaluated at each modelling stage, as well as a whole. The success of this case also proves that the adapted four-stage ontology modelling methodology (section 4.1) is feasible and sufficient for this cost case. Although it is originally claimed as general modelling methodology, the universality needs to be further justified with more cases in the future, such as different engineering analysis viewpoints.

5 Conclusion and Future Work

Efficient knowledge representation can naturally assist knowledge sharing and reuse, therefore aiding collaboration during the entire PLC. The proposed ontological annotation approach reported in previous work helps knowledge representation in supporting MEV. The work introduced in this paper builds on this reported work through a more robust and STEP-compliant anchoring mechanism, which strengthens the consistency and the interoperability across systems.

To integrate a new application as a total system involves modification and extension of the OntoCAD ontologies. This requires expertise and ontology modelling skill, but not necessarily software programming skill. A case study on cost estimation is an example of an EV that may be supported by OntoCAD. The development of the ontology in this context has been described and it has been demonstrated how an EV linked to an external application program can be established by following a modelling methodology and then integrating with existing ontologies without the knowledge and experience of software programming. By following similar process, other EVOs can be readily integrated too. However, the completeness of transferring the STEP standard to ontology is not the primary goal, neither to integrate as many applications as possible. We aimed to explore and develop an approach rather then providing a solution.

Concurrently with work reported here there has been research effort on reasoning over the knowledge base to derive new knowledge for downstream processes, but this will be reported in other papers. Other directions being considered include approaches to enriching semantics, multiple point anchoring and bi-directional/multi-directional anchoring.

Acknowledgment

The authors gratefully acknowledge the support of the Engineering and Physical Sciences Research Council (EPSRC), through the Bath Innovative Design and Manufacturing Research Centre, for the work described in this paper.

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A PPO Model-based Knowledge Management Approach for PLM Knowledge Acquisition and Integration

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Abstract: This paper proposes one model-based knowledge management approach, aiming to capture comprehensive knowledge from Product Lifecycle Management (PLM). Besides acquiring product information, we have adapted Product-Process-Organization (PPO) models to enrich the knowledge, in the perspective of long term preservation. We have extended CommonKADS knowledge engineering methodology as the framework to carry out PPO models, which are used to capture organizational, process and product knowledge from PLM. When extracted, the knowledge in different models will be merged, by using XML, into a comprehensive knowledge model. The knowledge model is designed based on the information package concept in Open Archival Information System (OAIS) reference model, which aims in long term digital preservation. The knowledge captured by the knowledge management approach will be archived and reused through our knowledge management system (an OAIS instance).

Keyword: Knowledge Management, Product Lifecycle Management, Model Transfer Process, KBE

1 Introduction

Digital information plays a significant role in production context when the digital preservation becomes one main objective of the construction and the maintenance of a production information system. However, regarding the product lifecycle management (PLM) aspect, the product life cycles are often far longer (e.g., aircraft - fifty years) than the expected lifetime of a manufacturing software application used to interpret the data (approximately three years). In spite of the application of traditional document engineering methods, the long term knowledge retention (LTKR) issues have been mostly neglected in traditional standard information life cycle implementations. The challenges of LTKR include legal, policy, organizational, managerial, educational, and technical aspects [1].

The LTKR is under the Knowledge Management (KM) context. KM is the practice of selectively applying knowledge from previous experiences of decision-making to current and future decision-making activities with the express purpose of improving organizational effectiveness [2]. For enterprises and industries, an archive of knowledge must capture all of the data required to completely define the product, and in some instances, processes [3]. Thus KM is not just a technology, but it is about people, processes and practice.

Researchers and engineers are developing diverse digital models and systems (e.g. LOTAR project [4，5], LTKR Work-shops [6], etc.) to be extensible and reusable for subsequent generations of technologists. The main objective of LTKR projects is to develop an auditable process for the long-term archiving of digital data (e.g. 3D CAD and PDM data) and metadata. However, these researches are lack of integration of organizational knowledge, process knowledge and the product engineering knowledge. Thus in our research, we propose a knowledge management approach for integration of product, process and organization knowledge, in the perspective of long term knowledge retention.

In the following sections, we will elaborate the process and models for knowledge acquisition and integration. Section 2 introduces briefly the model set of our proposed knowledge engineering methodology. Section 3 presents the knowledge acquisition models and process. Section 4 describes how the knowledge in different models merges into a knowledge model, which is used as basic knowledge object in the digital preservation platform. Section 5 shows one case study of knowledge acquisition and integration, by using our proposed methodology and models.

2 Model Set Structure of Knowledge Engineering

There are some opinions on how KM is performed. As we perform KM methodology on PLM information systems. And our KM methodology for LTKR dedicates to production knowledge, thus we have adapted the Product-Process-Organization (PPO) design model [7] concept, in order to identify and capture knowledge from PLM information systems. Our proposed KM methodology is described as the following general steps:

- Capture corporate organization structure and strategy: Organization Model
- Identify Business Process and products: Process Model, Product Model
- Identify knowledge for LTKR: Knowledge Model (knowledge container structure), mapping from organization, process and product model to preservation knowledge model
- Capture knowledge: Service design: Knowledge Extraction Service
- Create a knowledge-sharing culture: SOA design to establish dynamic connection to preservation platform

In [12], we have proposed an extended CommonKADS knowledge engineering methodology, whose model set is shown in Figure 1. This methodology supplies the PLM knowledge base with a set of model templates. The templates are constructed based on the knowledge management goal and production information system data structure. Although the model templates are identified in different levels of models (i.e. Context level, Concept level, Design level and Implementation level) and can be developed in parallel, driven by project objectives and risk. In the following section, we discuss the model transfer process from PLM systems to KM systems: The construction of PPO model (knowledge acquisition), and the merging of the PPO model to Knowledge Model (knowledge integration).

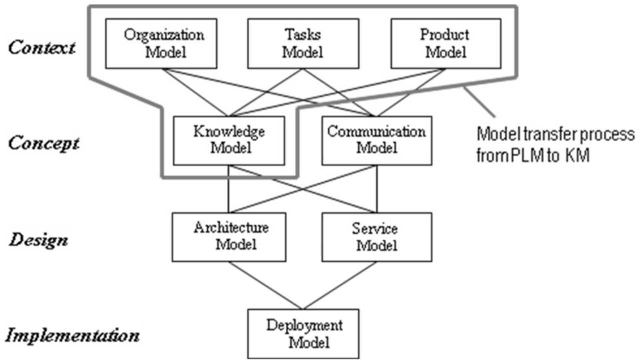

Figure 1 Extended CommonKADS knowledge engineering methodology – model set [12]

3 Knowledge Acquisition Approach

In PLM systems, the management and maintenance of product structure is one of the most important functions of the whole PLM system [13]. Modern PLM systems handle several product structures for the same product for different viewpoints (e.g. product structure is different from engineering point of view to manufacturing point of view). Thus we propose to formalize the product related knowledge by mapping from data in PLM systems to PPO model.

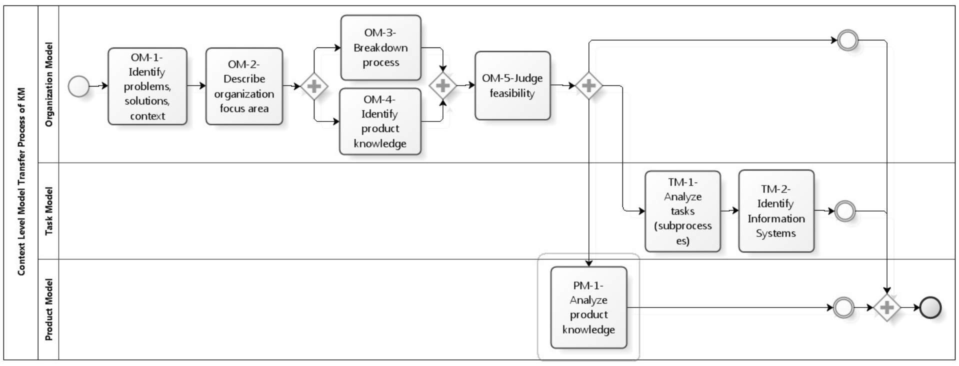

Figure 2 Context level: knowledge acquisition process

Figure 2 shows the knowledge acquisition process of Context level of our proposed knowledge engineering methodology. In extended CommonKADS methodology, modeling process supported by some documents:

- Organization Model (OM) is the scope and feasibility study and it describes and analyzes the broader organizational environment: 5 worksheets. The Organization Model represents the organization environment for knowledge management in the enterprise;

- Task Model (TM) focuses in tasks (sub-processes, breakdown of business processes) of PLM and identifies the information systems that operate the tasks: 2 worksheets. The Task Model represents the real tasks performed in enterprise, not the KM tasks;
- Product Model (PM) collects all product related information: 1 document package, whose format depends on the product engineering data representation and exchanging implementation method.

In order to establish the digital preservation platform, we have implemented one instance of the Open Archival Information System (OAIS) [8]. Thus in the preservation platform, the knowledge appears as the form of Information Package (IP), which is the knowledge model provided in OAIS. Therefore, the extracted knowledge from PLM system finally would be packaged in Information Package form for LTKR. In other words, the Knowledge Model will be constructed according to the Information Package structure. These activities of transfer knowledge from PLM system aims to enhance the interoperability of information systems, because our KM approach will be used not only in PLM system, but also in other information systems in enterprise. And our ideas of doing KM in enterprise are formalizing knowledge from different sources and synthesize them together for future use. However, in this paper, we just discuss how we perform the knowledge acquisition using PLM system as an example.

3.1 Organization Model

The worksheets OM-1 to OM-5 are used for interviewing knowledge decision makers, who is responsible for KM approach, in organizations, or analyze the information system organizational structure in the enterprise. Then, the outputs from the model are the list of the knowledge intensive processes and product knowledge assets which are related to each process. Finally, the feasibility of the knowledge management project was analyzed to see if the project was feasible in terms of business, technique, project and solution. It serves as a decision support for an economical, technical and project feasibility study, in order to select the most promising focus area and target solution [11]. The five worksheets are show in Figure 3 (OM-1 to OM-5). In general, the OM worksheets are basically respecting the CommonKADS methodology, but dedicates to product and PLM.

- OM-1 analyzes the KM project problem (e.g. long term digital preservation) and organizational context (i.e. enterprise strategy, goals, missions, and important external factors, etc.), and lists possible solutions and technologies that could be adapted.
- OM-2 represents single problem solution of OM-1, and contains information regarding the organizational structure, business process, product and knowledge.
- OM-3 identifies the business process, and breaks down the process, which is concerned in OM-2, into tasks (sub-processes). And in the same time, OM-3 identifies the corresponding products and information systems of the tasks.
- OM-4 identifies each product, which is introduced in OM-2 and OM-3. OM-4 specifies the corresponding source information system for the product.

- OM-5 is a decision-making support document, which summarizes OM-1 to OM-4 worksheets, and focuses on business, technique and project feasibility. And then it proposes actions, risks and constraints of the KM project.

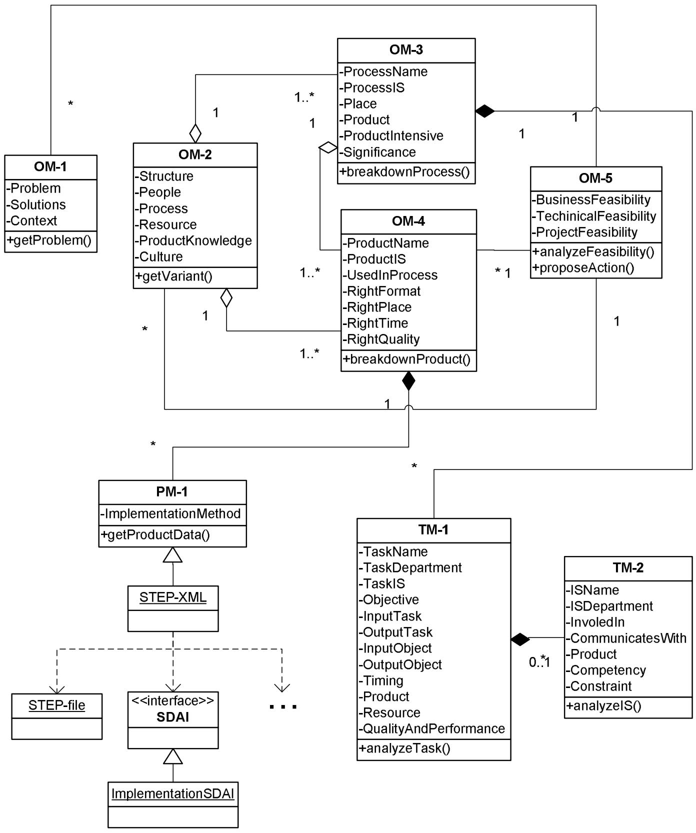

Figure 3 Context models: Organization Model worksheets, Task Model worksheets and Product Model

The Figure 4 shows part of one example of OM-3 worksheet. It represents the process that performing in an airfoil design phase in enterprise, and it breaks down the process into several tasks and identify the data used in each task.

Organization Model: OM-3 - Process Identification and Process Breakdown (to task)						
Solid modeling of Airfoil 2530LDRY						
No.	Task Name	Information System	Location	Product Information	Intensive	Significance
P-1	Idealization	Solid Works	Design Dept.	3D drawing of airfoil	Yes	23
P-2	Surface approximation	Solid Works	Design Dept.	3D drawing of airfoil	Yes	21
P-3	Digitization	Solid Works	Design Dept.	3D drawing of airfoil	Yes	25

Figure 4 Example of Organization Model: OM-3 Process Breakdown

3.2 Task Model

The task model is a refinement of knowledge intensive tasks identified in the organization model. For investigating a task, three viewpoints are concerned in this model. The functional view divides a task into subtasks: input and output. The static information structure view is a description of the information content and structure of objects that are handled in the task. The control view (or dynamic view) provides understanding about triggering events, decision-making points, and other knowledge about the time aspects. The two worksheets are shown in Figure 3 (TM-1, TM-2).

- TM-1 aims at refining the task within the target process. The three views of tasks are addressed by this worksheet.
- TM-2 is a specification of the information system or sub-functions of an information system, where the target task performs. This worksheet, which concerns information system, is quite different from the original CommonKADS methodology, because we propose a methodology that is dedicated to production related digital preservation.

3.3 Product Model

The PM-1 document is a specification of the product knowledge employed for a task, and possible bottlenecks and areas for improvement. In PLM systems, the product model is the most obvious and easy-to-captured. In fact in most PLM information systems, there are already specific data structures for product. The composition of product model will cover the following aspects but not limited according to specific product: component, function, behavior, structure, interface, specification and metadata. This worksheet structure depends on the product data structure in information systems.

In product data exchanging field, as we have introduced, the standard ISO 10303 STEP is adapted. And STEP-file (ISO 10303-21 Clear Text Encoding of the Exchange Structure) is widely used as the exchanging form of STEP. The mapping of engineering data is described in EXPRESS (ISO 10303-11), so the extracted product data could be manipulated easily by using STEP Application Protocols. Besides, there are several implementation methods of STEP to extract product data, and there are tools to support them. One other way of extract product data from information system is by using STEP-XML (ISO 10303-28: Industrial automation systems and integration—Product data representation and exchange—Part 28: Implementation methods: XML representations of EXPRESS schema and data). STEP-XML uses XML to represent EXPRESS schema. Although from the file structure point of view STEP-XML is not as concise as STEP-file [14], product information in XML file is easier to integrate with organization and process knowledge.

In our research, we use tool to extract product data from information system, and at last we convert the product data into STEP-XML and to integrate with organization and process knowledge. The extraction tools' types depend on the information system. For example, EPM EXPRESS Data Manager could be used for extracting product data from PTC Windchill and forming data into STEP-file. And by using STEP-file XML translator (e.g. PDES StepXMLTranslator [15], etc.) we could get STEP-XML file of the product. As it's shown in Figure 3, STEP implementation methods and tools would be used in information system, and at last the product data files are converted into XML as our

Product Model. We propose that both the worksheets in Task Model and Organization Model will be also encoded into XML by using METS (Metadata Encoding and Transmission Standard), so as to integrate the three Context models. The reason we propose using XML is that the product data could be described in STEP-XML, and if the other worksheets are also generated into XML files, we could use XML database to manipulate the content in XML files easily.

3.4 Knowledge Model

The Knowledge Model is an extension of Information Package model from OAIS. The structure of IP (Information Package) model is defined in [8]. IP is a package containing data objects as well as comprehensive metadata to describe the data objects. The product data will be preserved as data objects, while the IP itself is task-oriented. In Descriptive Information of the IP, the usage of the IP (i.e. task objective of IP) is described based on the analysis in Task Model. Thus the end users of the preserved IP would locate the corresponding knowledge by their working requirements. For example, if one end user tries to find information about core design of a power transformer in the critical design phase, his/her task objective is “core design”. And by searching Descriptive Information with this task objective, all the corresponding IPs would be located. As we have proposed to manipulate the acquired knowledge in the format of XML files, we will get at last XML files (i.e. Representation Information, PDI, Packaging Information and Descriptive Information files) as metadata for IP.

4 Knowledge Integration Mapping

We could notice that the KM process in Context level is in a top-down strategy. Thus either Task Model or Product Model is identified in Organization Model. And in this manner, it’s not too difficult to establish links to merge the Context models (Figure 3). And the outcome of the previous models and worksheets will provide not only clear idea on the target knowledge for PLM long term preservation, but also comprehensive knowledge on enterprise organization, business process and product engineering knowledge.

The worksheets act as checklist and information archive, and they should be used flexibly. In archival system, the worksheets are easily to convert from or to XML format. The product model document may also be represented in XML. By using XML, we could integrate the product knowledge with organization and process knowledge, in order to capture comprehensive metadata for long term preservation. According to the KM approach and worksheets structure, we have developed our XML Schema for generating XML files from worksheets. And we provide these XML files as the knowledge source of construction of knowledge model. Figure 5 shows the mapping from Context models to knowledge model.

The knowledge integration mapping in Figure 5 is from the left side to the right side. According to the mapping shows in Figure 5, not all the worksheets are converted into XML. OM-1 and OM-5 are decision-making documents in our KM project, while other six documents are source knowledge for integration. Thus the source knowledge documents are converted into XML files and are put in XML database, so as to be operated. Based on the IP structure, we query corresponding information and compose the information as the components in IP. All the components are generated into two XML files (i.e. PDI: Preservation Description Information, Representation Information), which is the metadata of the product data object. And at the same time, the product data object is saved, too. The linking information of product data and metadata is described in Packing Information. And at last the Descriptive Information is generated as we have stated in the previous section.

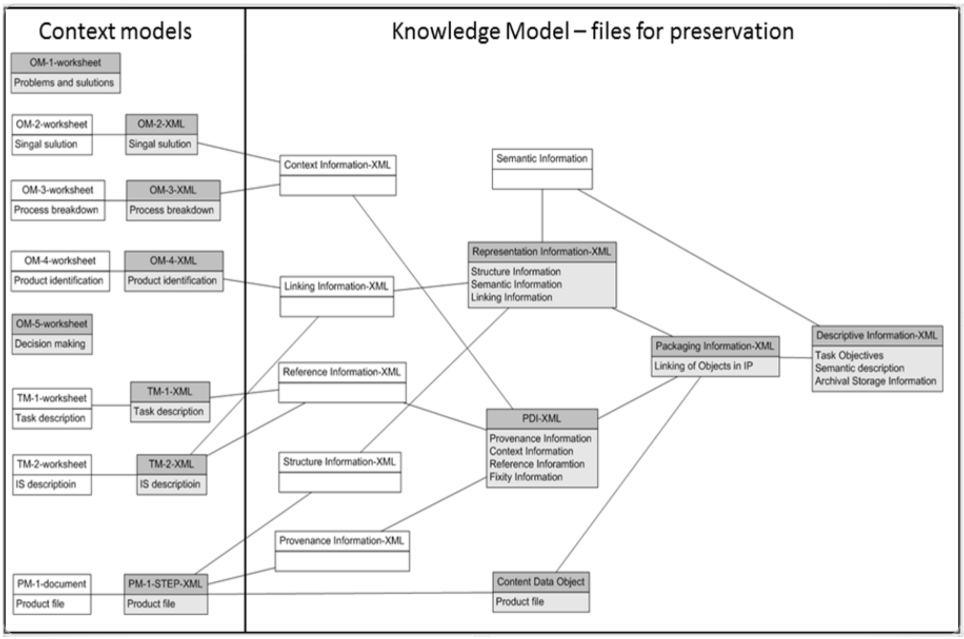

Figure 5 Knowledge integration mapping: from Context models to Knowledge Model

From our survey and information collection about the transformer product life cycle, we have gained mass of information related to the product. We processed the mass of information through the model transfer process (Figure 2). In the Organization Model and Task Model domain, by filling the worksheets (worksheets' structures are described in Figure 3), we get seven worksheets. The OM-3 worksheet is shown in Figure 4. And the worksheets would be converted into XML files based on the XML Schema we have created for each worksheet (Figure 6).

In the other side, the CAD drawing of the product (an airfoil) is extracted as a STEP-file. Because in our case study, we don't have STEP-XML of the product directly, we need to convert the STEP-file into XML, so as to integrate with other XML files. The XML files are added into an XML database (in our case we use BaseX 6.5.1 [16]). According to the mapping we have discribed in previous section, corresponding information in the XML files is queried and composed as four XML files, which are the metadata of the product document. And when archiving, we could archive either STEP-file or STEP-XML file as data object, according to enterprise strategy. In our case, as we have no directly translator from 3D drawing to STEP-XML, we prefer to archive the STEP-file as data object.

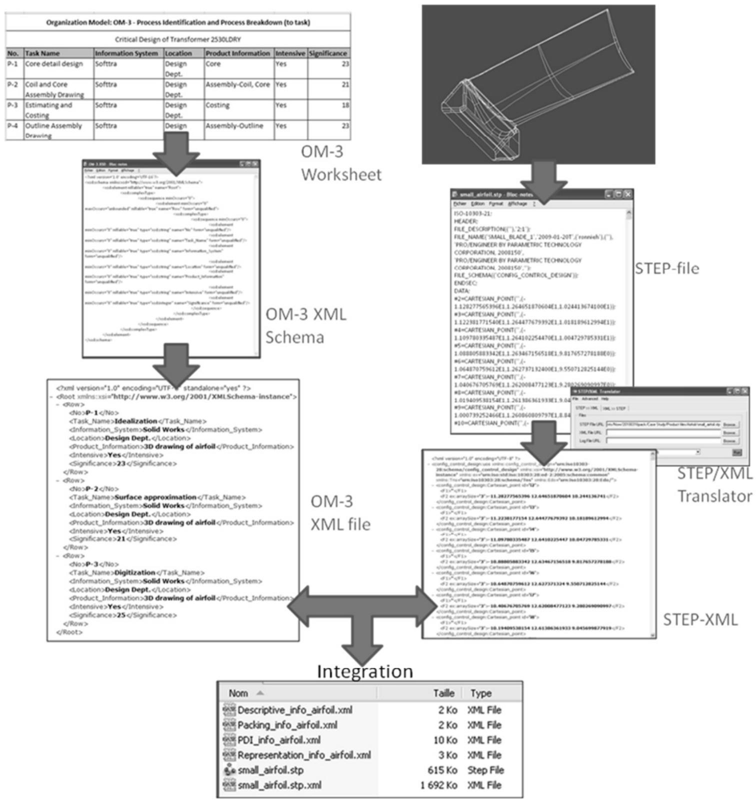

Figure 6 Case study – knowledge acquisition and model transfer

5 Conclusion

We propose one model-based knowledge management approach, aiming capturing comprehensive knowledge from Product Lifecycle Management (PLM). Product-Process-Organization (PPO) models are adapted to enrich the knowledge, in the perspective of long term preservation. We modified the KM processes defined by CommonKADS, in order to adapt PPO models. In our proposal, in Context level, we use Organization Model to analyze enterprise KM requirements and business structure. After that, we use Task Model to represent the processes in PLM. At last, we adapt methods from product data representation and exchange standard STEP (ISO 10303) to formalize and extract product data as Product Model. And the knowledge in different models is merged, by using XML, into a comprehensive knowledge model. The knowledge model is designed based on the information package concept in Open Archival Information System (OAIS) reference model, which aims in long term digital preservation. The knowledge captured by the knowledge management approach will be archived and reused through our knowledge management system, which is a digital preservation system we have built based on OAIS reference model.

The future work aims to transfer the KM approaches into services using Service-oriented architecture principle, in order to enhance the interoperabilities of each function and the KM system. By doing this we will make sure that our KM system be dynamic to adapt the long term technical and organizational changes.

Acknowledgment

This research work is supported by the research group Cluster GOSPI. Authors would like to acknowledge the Cluster GOSPI, as well as the members in the laboratory LIESP of Lumière University of Lyon.

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A "high productive design methodology" integrated in a PLM context using Knowledge Configuration Management

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Abstract: *This paper presents a global methodology developed for modular product modeling based on design rules and standards capitalisation, connected to the information management system of a company. An application of our self-developed collaborative tool is proposed to integrate a knowledge capitalisation approach in the PLM architecture of the product. Our Knowledge Configuration Management tool also integrates the use of knowledge in a project context in order to create knowledge configurations of the product, considering process constraints. The main goal is to define various modular products using these knowledge configurations in order to determine several design possibilities. Assembly sequence generation techniques based on knowledge is the focus of the research. This approach aims to develop and experiment a "high productive design methodology", taking into account the modularity of products and also the knowledge associated, in the framework of Design For Assembly methods (DFA).*

Keywords: Product Lifecycle Management, Knowledge Based Engineering, Knowledge Configuration Management, Modular design, Parametric modeling

1 Introduction

The integration of the lifecycle knowledge and "know-how" throughout the product lifecycle is more and more considered in industrial organizations. The goal of the Product Lifecycle Management (PLM) strategy is to maintain coherence between actors and steps which are involved in products development, where all actors have to participate and maintain this coherence [1]. Many researchers reported their research finding in this topic, either on tools and methodologies of information exchange [2], others on interactions between users and CAD tools [3-5]. The knowledge integration associated to processes in the product lifecycle is also reported in the earlier publications [6-8]. The knowledge formalisation and re-use during design projects allow to avoid decision mistakes and to ensure the design quality of 3D CAD models in order to "Design/Draw right at the first time". This approach allows designers to capitalise the "know-how" in their organization and more particularly design rules, in order to determine the product and process feasibility, and to generate new parameterized CAD models. In this paper, we are interested in the integration of the “known-how” in mechanical system design considering manufacturing process constraints. We suggest a methodology that allows concurrent management of Knowledge capitalisation and Knowledge Configurations update (including parameters, design rules…) as well as their use in a project context, thanks to the availability of KBE (Knowledge Based Engineering) systems. Our method takes into consideration of the product functions, its assembly constraints and integrates the expert knowledge in the early design process. In order to illustrate the effectiveness of the developed methodology, an experimental case study of a pneumatic scraper is presented in the paper.

2 Literature review: Product design methodologies

Design methods, within the framework of engineering design process, have been described by many authors in order to reach a solution by starting from a request, or in order to define a detailed product specification by starting from a concept. These methods aim to build various sequences of design activities to be performed by different design actors (marketing, industrial design, design office, production ...) to achieve a final goal: a marketed product that meets the customer needs. Among the many models of product-lifecycle design process in the literature, it is possible to classify these models into two types namely: sequential models or concurrent models. Sequential models of the product lifecycle process such as Systematic Design model [9], Ullman design process model [10] or Total Design process model proposed by Pugh [11], divide the design activities into phases or tasks that follow each other. With the evolution of industrial constraints such as the need to increase quality while reducing costs and time and the evolutions of digital tools and communication infrastructures have contributed to the development of new design organizations and models. These new models of design process have been also called concurrent [12], simultaneous, integrated [13], distributed [14], or collaborative engineering. Characteristics of these various methods are the integration of Design For X constraints related to the product entire lifecycle, a parallel realisation of the tasks required to perform the design process, etc. Therefore, the design process has also been improved towards a multi-dimensional and multi-function design process because project managers can consider many perspective of view coming from various domains. Yan [15] proposed to model a product or system from multiple perspectives in order to generate a complete virtual model representation of the product to support multi-life phase design decision exploration and decision making. Among the models of concurrent engineering, and through the "axiomatic design" approach, we have identified another way of improving the product design process, if designers decide to respect specific rules, also called axioms. This axiomatic approach is based on various axioms (example: axiom of independence, axiom of minimum information, etc.) and Design domains (Customer Domain, Functional Domain, Physical Domain and Process Domain). Another approach concerns also the multi-viewpoints model of the product considered as an integrated design method of products or mechanical systems [13]. This approach is based on the product architecture and on the combination of various viewpoints of the system: functional, structural, geometrical, assembly, etc. A new design process model, developed by our research team, and called Multi-domain and Multi-viewpoints design model [16], can be described as a collaborative design process model, integrating concepts coming from Axiomatic design and multi-viewpoints model. Concerning the theoretical models underlying the design process, three kinds of models can be used: the perspective models, the computational models and the knowledge based models [17]. This paper is concerned with the scope of computational models, requiring the use of computers to determine the best feasible values of design variables, using Constraints Problems Solving, when considering expert knowledge (parameters, rules, etc.) linked with the CAD model of the product.

3 Methodology proposed

We are interested here, by the decrease of time devoted to routine design, in the development and the integration of a knowledge configuration management approach in a collaborative tool, called "KrossRoads". This approach using "KrossRoads" tool allows to formalize and centralize the company "know-how", thus to simplify the use of this "know how" during the product development. As described in Figure 1, we developed at M3M laboratory a global methodology. In this paper, we will focus on three steps:

- Formalize and centralize the "know-how" in a database integrated in a collaborative tool,
- Use the "know-how" in a project context of DFA applied to modular products,
- Generate or use application based on Knowledge Configurations, defined in a previous step, to define the 3D model.

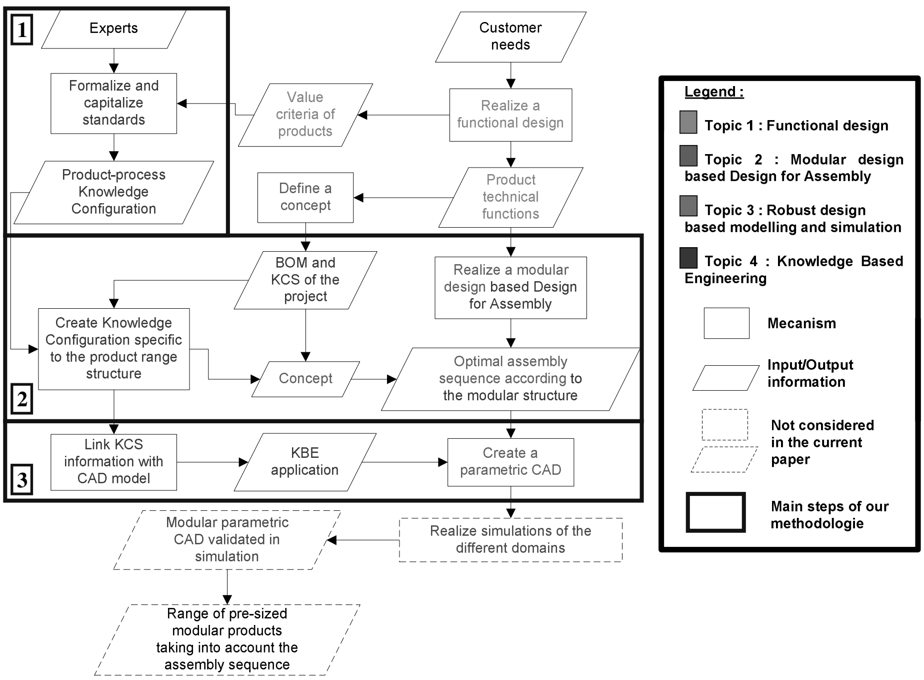

Figure 1: Focus on three steps of our global methodology

These three steps, which will be explained in the next section, are integrated in the global methodology dedicated to a "high productive" design method for modular product development, in a PLM context. Our approach will allow managing the integrated knowledge regarding the modular products development for each application case or variants. In this paper, we are particularly interested in a part of the global methodology, which lean on the KrossRoads tool. KrossRoads software environment is specified and developed at M3M laboratory.

3.1 Formalisation and centralisation of the « know-how »

This first step is dedicated to company experts. If experts want to capitalize and use this « know-how », it is important to formalize it. Some workbenches of the "KrossRoads" tool are dedicated to formalize the expert's know-how. We are interested, in our case, by rules which are important during the design, for example:

- Process rules linked to the product feasibility.
- Design rules linked to the product design,
- Some standards and values imposed by purchase department in order to reduce the component variety.

We can extend this list to all information relating to a product or a process that can help the designer to avoid design mistakes from the beginning to the end of a project. We choose to formalize this « know-how » in a database. Figure 2 shows a part of KrossRoads UML model used to determine the organization of the database.

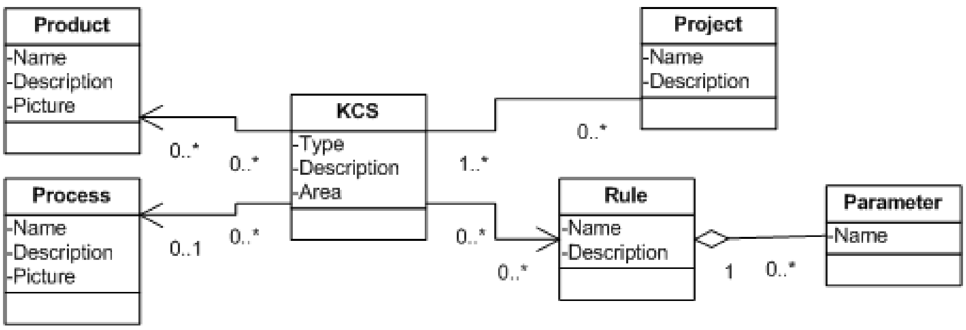

Figure 2: UML model describing a part of KrossRoads concepts

The class "Product" represents all components designed in a company. The class "Process" indicates all processes used by the company: manufacturing process, assembly process, etc. Each item of the "product" and "process" class is defined by a name, a description and a picture. The lists of products and processes are represented by a breakdown structure. "KCS" class represents a group of rules that will be reference entities called "KrossRoads Check Sheet" (KCS). Each KCS is defined by a type, a description and an area. In our case, three types of KCS are defined. The type means that the KCS is composed by an association between products and process items. The first type is the "KCS Product", this KCS is composed by rules which are common to all configurations of a component. The KCS is associated to one or several product. The second type is the "KCS operation" which is composed by rules corresponding to a optional process applied on a component, this KCS is composed by an association between one process and zero, one or several components. The last type is the "KCS Assembly" where users can find all rules dedicated to an assembly process between several components, this type is composed by an association between one process and two or more products. Each KCS is also associated to an area. In this context, an area represents a geographic area where is applied the KCS. These KCS will be displayed in the form of a "Check List" which is a group of successive rules to check. Each rule is defined by a name, a description, a picture and zero, one or several formulas including parameters. As explained in the previous paragraph, we will find some standard values, list of values, matrix or even some equations. Experts can create groups of rules for each components, process or assembly that correspond to our three types of KCS. The goal of these types of KCS is to have only the right rules that designers need during a project. A specific workflow, allowing the KCS and rules validation, will be also available in our tool. This workflow is divided in two steps: technical validation and management validation.

3.2 Use in project context

After the Knowledge formalization, we suggest creating in this tool, a specific workbench dedicated to people intervening during projects, and more particularly design engineers and CAD designers. Users may use existing information available in the database during their projects, for example in case of a new product development. In KrossRoads, design engineers can create a specific area dedicating to a project where they can instantiate a list of KCS. This list of KCS will be specific to the selected project. The right part of the UML (**Figure 2**) shows the class "Project" where will be stored the instantiated KCS. At the beginning of a project, a design engineer has to define the product classification, also called "Bill Of Material" (BOM). The BOM can be created directly in the tool or with an upload from the PDM tools. The definition of the BOM has to take into account the several configurations of a product during a project. The goal here is to generate, thanks to the BOM, a first list of KCS, and more precisely a group of specific rules regarding a project per product configuration or variant. Each item of the BOM will be associated or not to one or several KCS. Some KCS can be automatically instantiated for each component, such as KCS Product, others will be optional, like KCS operation because it is an optional process, but also "KCS assembly" because user has to choose between several assembly processes. The user has the possibility to instantiate or not these KCS inside the project. Using these groups of rules during the product development, the user ensures the feasibility of the product and can validate the design. A manual deviation management is also included in the tool, which allows a follow-up of each non-complied rule. In this part, we can automatically create a Knowledge Configurations which correspond to a list of KCS, associated to each BOM item. At the first level of the BOM, the Knowledge Configuration corresponds to all KCS and rules applied in the selected project. A capitalization phase of each parameter value, using rules, will be included. That allows Knowledge Configuration traceability and gives the possibility to create a database of all old projects. At the same time we can create a specific search tool to improve the reuse of validated components.

3.3 KBE Applications

To improve the use of knowledge and automate rule checking during a project, Knowledge Based Engineering (KBE) applications are used or generated, from knowledge Configuration. In this context KBE applications allow to create applications that enable engineers to specify requirements or create designs on the basis of the knowledge capitalized in the database. The main role is to bridge knowledge management and design automation. A friendly interface is developed in the same time to help users to use KBE applications. Two different cases can be defined: "case 1 – A standard parameterized model exists in the company" or "case 2 – No parameterized model exists in the company". In these two cases, the creation of KBE applications is managed at two different levels. In the first case, the application is linked to a parameterized CAD model and allows obtaining a first CAD model. The designer can change the value of parameters. In the second case, no CAD model exist, a 3D CAD model can be generated with a skeleton with parameters and rules directly integrated. The designer can use this skeleton to design the 3D model and attached the geometry to existing parameters.

4 Experimentation

In this section a real experiment is performed on a pneumatic tool: a scraper. This product can be embodied in several configurations following the initial specification. The goal is to define specific Knowledge Configurations for each various modular product. To simplify this example, we will take only three different configurations (**Figure 3**).

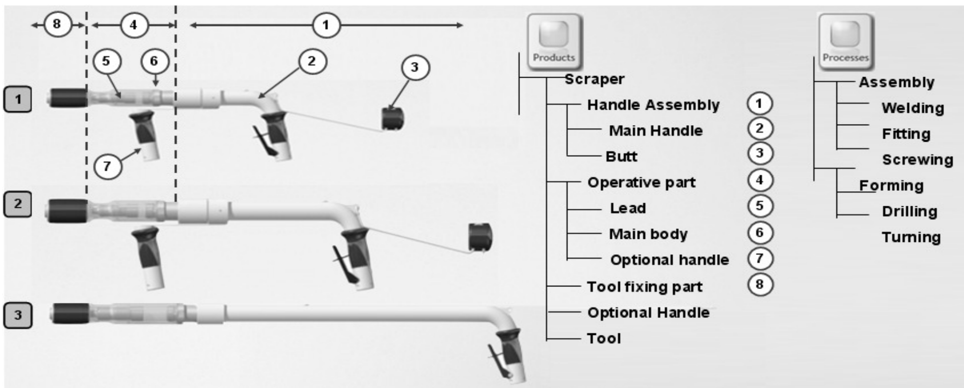

Figure 3: Examples of configurations & standards names

4.1 Formalization of Know-how.

In this first step, the goal is to centralize the "know-how" regarding the scraper in a collaborative tool. We have divided the formalization in four steps:

- Define the list of components with standard names.

- This list (**Figure 3**) is used in other tool like PDM & CAD tools during the product development. It allows creating correspondences by similarity name between tools.
- Define the database architecture. The definition of the database is done when we define the "Product", "Process" and "KCS" class in our UML model. In our case, we use a product breakdown structure, which use the standard name defined in the first step, and a process breakdown structure, where all processes used in the company are capitalized.
- Create generic KCS entities.

When an expert creates a KCS entity, he defines a type and associates it to one or several item of the products-process breakdown structure. In our case, we define three types of KCS: product, operation and assembly. In this example, as illustrate in **Figure 4**, we create only four KCS, two KCS product, (the lead and the optional handle), one KCS operation (regarding the boring process on the lead) and one KCS assembly (regarding the assembly between the main body and the optional handle).

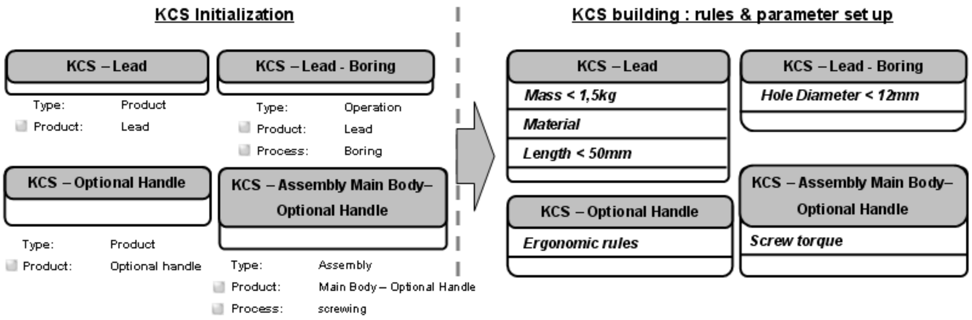

Figure 4: Examples of generic KCS entities

After the creation of KCS entities, the experts can fill KCS with rules and parameters (**Figure 4**). The goal is to create specific groups of rules regarding a product, a process or an assembly. We can find, for example, in these KCS some rules about the mass of the lead, the list of value for the material, or the ergonomic rules on the handle.

	Phase 1			Phase 2					
Project variant	1	2	3	1	2	3	KCS Type		KCS Instance
Bill Of Material									
Scraper	x	x	x	x	x	x			
Handle Assembly	x	x	x	x	x	x			
Main Handle (1)	x	x		x	x				
Main Handle (2)			x			x			
Butt	x	x		x	x				
Operative Part	x	x	x	x	x	x	Assembly	✓	KCS Assembly Main body - Optional handle
Lead (1)	x			x			Product	✓	KCS - Lead
							Operation	✓	KCS - Lead - Boring
Lead (2)		x			x		Product	✓	KCS - Lead
							Operation		KCS - Lead - Boring
Lead (3)			x			x	Product	✓	KCS - Lead
							Operation		KCS - Lead - Boring
Main body (1)	x	x		x	x				
Main body (2)			x			x			
Optional handle	x	x		x	x		Product	✓	KCS - Optional Handle
Tool Fixing Part	x	x	x	x	x	x			

Figure 5: Global BOM and associated KCS for different phases and steps of the design process

4.2 Use in project context

When a design engineer starts a new project, he needs to get all knowledge associated with the new product development. It allows avoiding risks and ensuring the design quality. In this example, three types of scrapers are made available from previous design. The goal is to extract from each scraper, from the database, the KCS that the designer needs to design the product. At the end, we obtain a list of KCS specific to each project variant. We can define two steps in the definition of this list.

The first step is to define the BOM in KrossRoads or import it from PDM tool. The BOM has to be defined for all variants. To define variants, a designer can use a matrix to indicate where a component is used in which variant. After defining the BOM, the user can filter it and obtain specific BOM per variant. At the same time, a first list of KCS is automatically suggested. Some KCS will be automatically selected (KCS product), the user will have the possibility to select others KCS (KCS Operation – KCS Assembly).

Figure 5 illustrates an example, where a user can find in the first column, the imported or defined BOM. In the next column, the user can define where components are used. In this case, we can remark that we have three variants with different leads. The optional handle is only available in the variant one and two. The column "KCS Type" indicates the type of the KCS. In the next column, the user can choose the KCS that he wants to instantiate in the project (case highlighted in grey are automatically checked). It is also possible to define several steps of the design process during the project (Phase 1: request for quotation, Phase 2: development). In this first version of the tool, the user can just create manually a list of KCS; the BOM import is still in specification phase.

After the validation of the KCS list, it will be possible to filter the BOM per variant and see easily all attached KCS. As shown in **Figure 6**, we can see the BOM associate to the first variant. A Knowledge Configuration can be automatically created for each item of the BOM and regarding the variants.

	Phase 1			Phase 2					
Project variant	1	2	3	1	2	3	KCS Type	KCS Instance	
Scraper	x	x	x	x	x	x			
Handle Assembly	x	x	x	x	x	x			
Main Handle (1)	x	x		x	x				
Butt	x	x		x	x				
Operative Part	x	x	x	x	x	x	Assembly	✓	KCS Assembly Main body - Optional handle
Lead (1)	x			x			Product	✓	KCS - Lead
							Operation	✓	KCS - Lead - Boring
Main body (1)	x	x		x	x				
Optional handle	x	x		x	x		Product	✓	KCS - Optional Handle
Tool Fixing Part	x	x	x	x	x	x			

Figure 6: A specific BOM limited to the first variant for different phases of the design process

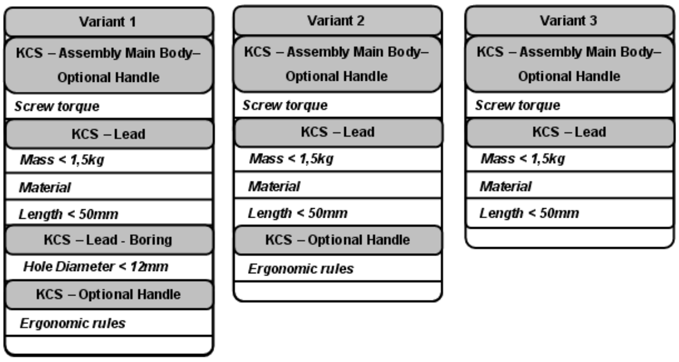

Figure 7: Knowledge Configuration per variant of the product (rules and parameters)

Figure 7 shows a simplified representation of the Knowledge Configuration at the project level for each variant. Various rules and parameters are considered in each KCS.

4.3 Using Knowledge Configuration

In the last step, knowledge configuration can be used to generate KBE applications for each variant. It can be seen in **Figure 8**, an example of KBE application. This application is use in order to define the energy and the frequency of each impact of the scraper product, considering the various design parameters of the Main body and of the Lead.

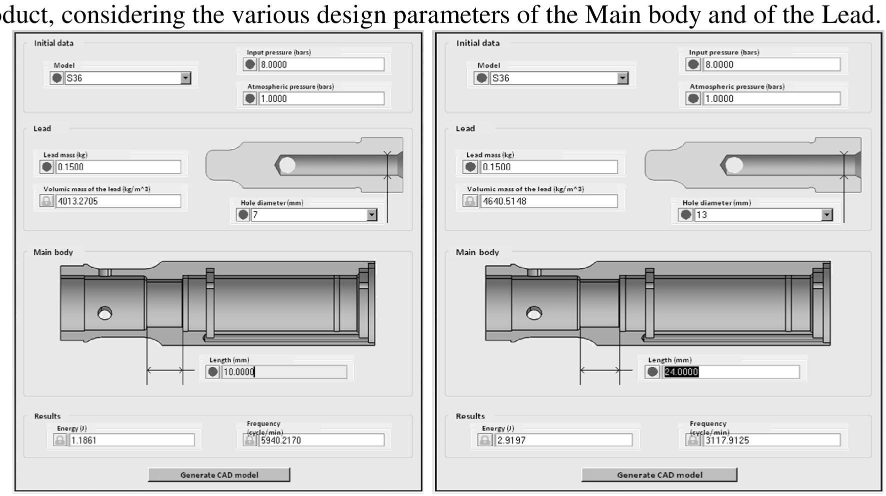

Figure 8: Example of KBE application focused on the main body and the lead of the scraper

In this case study, knowledge configurations included in different BOM are defined for each variant of the product. Moreover the specific BOM for each variant can be used to generate assembly sequences for modular products. To complete this step, a new action must be performed. This action consists of the definition of adjacency matrix between components. A matrix of adjacency contains two types of oriented links: contact relationships (representing an oriented physical contact between two components) and precedence relationships (representing a link between two parts without any physical contact, providing an assembly order constraint, despite the lack of contact between two basic components).

5 Conclusion and perspectives

The development of KrossRoads is currently in progress at M3M laboratory at UTBM. The architecture of the database can be applied to various companies. We can also improve its functionality by giving the possibility to customize the tool's architecture, such as for instance, the database or the KCS type. Currently, only a first database, organized by products and processes, is created. The link with the CAD and PDM tool is not developed yet, but specifications have been defined to develop this link. But first tests have been done to generate a KBE application. This first version is also tested in a worldwide car manufacturer company; we can remark a best integration of knowledge during product development. It will be possible to decrease product development time when the link with other tools, involved in the PLM strategy of the company, is established. First results are promising as the methodology and our Knowledge Configuration Management tool have proved to be effective. This leads to the identifications of other functionalities. For example, it would be interesting to link this kind of tool with a 3D search tool in order to improve the reuse of validated product at the beginning of a project. Another potential area is the link between the knowledge configuration and the costing and the planning of the product.

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Managing the Product Configuration throughout the Lifecycle

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Abstract: Companies have to engineer, manufacture and distribute innovative products at best quality and they must dynamically adapt to new and changing global markets. Globalization is not the only trend companies are faced. To increase their competitive position in today's global marketplace, companies have to control the product development process and the growing complexity of products. Product updates, design changes, recalls and unproductive work are examples caused by inefficient information sourcing. Configuration Management (CM) as a core process within Product Lifecycle Management (PLM) has the task to implement and monitor such complex changes influenced by customers, suppliers and other engineering stakeholders on all disciplines within the supply chain.CM assures the consistency of each product in terms of managing the influence between requirements, functional and physical characteristics, design and documentation. But a number of challenges have to be solved technical and organizational, before CM can be implemented in a company successfully.

Keyword: Product Lifecycle Management (PLM),Configuration Management (CM), Engineering Change Management (ECM)

1 1 Introduction

To increase their competitive position in today's global marketplace, companies are facing a host of increasingly complex challenges that, taken together, have the power to make or break an organization going forward. Just consider the following trends:

- Adapt to new and changing markets.
- Reduced cycle times, cost pressures and growing requirements
- Permanent transformation of the product development process. Result from changing market conditions, requirements for the product or from a customer perspective.
- Increase of product complexity as a result of a growing "multimarket".
- Growing globalization of value chains and a growing use of interdisciplinary communication technologies, and problems of inconsistent communication between constituents located in different cultures and time zones.

The sum of these factors is causing a far-reaching change of requirements regarding methods and IT solutions for the product development process. All of these methods are in pursuit of a common approach to supporting the complete product lifecycle, from the very early phase of requirements collection, down to end-of-life recycling across all disciplines (mechanical engineering, electric/electronic engineering, software, and services) across departments and locations (Image 1) [3, 4, 5]. On an IT level, the aforementioned methods are supported through modern authoring systems (CAD, CAM, CAE), as well as through corresponding simulation and visualization technologies. PLM (product lifecycle management) solutions are hereby providing the functional and administrative backbones. Configuration Management (CM) as a core process within PLM has the task to implement and monitor such complex changes influenced by the multi-disciplinary product development process shown in Figure 1. But before CM can be implemented in a company successfully a number of challenges have to be solved technical and organizational [3].

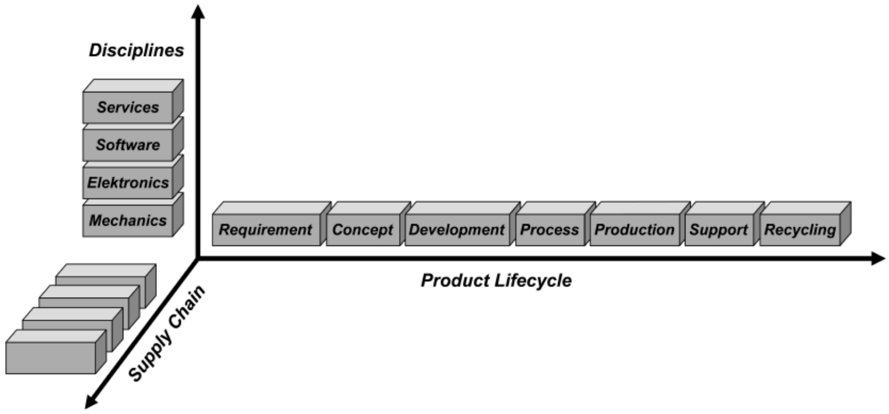

Figure 1 Multi-disciplinary product development [3]

It is necessary to define the role of CM around the growing complexity of products. According to this it is also necessary to define the trend of CM across the industries and get an answer about the consideration to implement a successful CM. Finally a outlook about CM as future business driver.

2 Definition and Role of Configuration Management (CM)

The driving factor behind the current need to optimize Configuration Management (CM) revolves around the growing complexity of products. CM was originally developed as a solution approach in the 1950's in the Aerospace industry. To understand the inner machinations of CM, it is necessary to have a look at its prerequisites;

- The product model and the product data management based on it, and
- The process model and the process management based non it. [2, 4, 5]

Product models have the objective of representing products, including all relevant related information across the complete lifecycle. A product model consists of the component of product master data, which, on an attribute level, is represented through an identifying number, potentially a classification, a revision (or version) and a denomination. The product model is complemented by a product structure and the related documents. For a number of reasons, product structures are defined in a variety of different approaches, usually referred to as “views”. The representations in Figure 2 show views of the product structure across the product lifecycle.

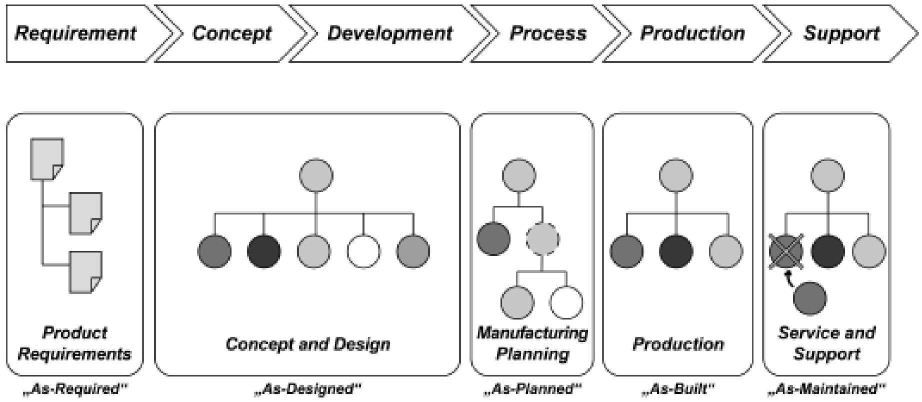

Figure 2 The product structure in different phases of the life cycle

There is also a relationship between product components and documents. Every document entry (meta data) can itself be connected with any given number of files, e.g., CAD native or neutral formats. With regards to parts’ and documents’ numbers and revisions, there is a variety of implementation approaches defined by whatever organizational approach is adopted by the individual enterprise.

The ***process model*** in the environment of product development describes the representation of technical and organizational business processes. Processes are typically represented graphically as status and transition diagrams (Figure 3).

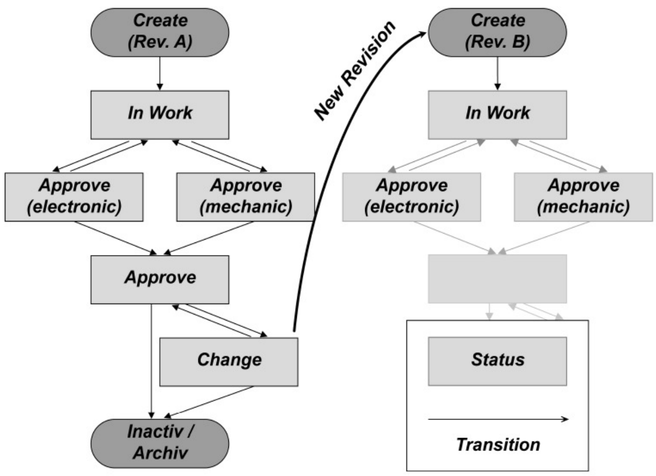

Figure 3 Release and Change process.

Processes are applied to the elements of the product model. By applying the rules, relationships and control mechanisms, the consequences of changes to the managed product are automatically followed through. Within the model there is documentation of:

- where the part is used,
- who designs, manufactures and supplies it,
- who initiated or declined a change request,
- when the change was implemented,
- when the change went into production, and
- why the change was made.

The identification of a production baseline is enabled through the so called Effectivity. It represents the period of validity of the configured product components and documents. Depending on the type of individual representation, it is defined by:

- The date or the revision (primarily consumer goods or products manufactured in high volume)
- Or, additionally the so called serial number. This is a continuous number to identify every item, assembly or part.

A configuration model enables the derivation of any given design, manufacturing, delivery, or operating baseline. The focus is on the creation and reconstruction of a product definition. Configuration management represents, on the one hand, the relationship between product data and documents, and, on the other hand, the varying product configuration across a time-limited change index or a serial number [2, 5].

ANSI (American National Standards Institute), in collaboration with EIA (Electronic Industries Alliance), has published the following definition of CM, which is widely recognized as a standard: "Configuration Management ... is a management process for establishing and maintaining consistency of a product's performance, its functional and physical attributes, with its requirements, design and operational information, throughout its life." The latest internationally accepted definition is represented by ISO 10007 (2003): "configuration management coordinated activities to direct and control configuration" in which configuration denominates “interrelated functional and physical characteristics of a product defined in requirements for product design, realization, verification, operation and support".

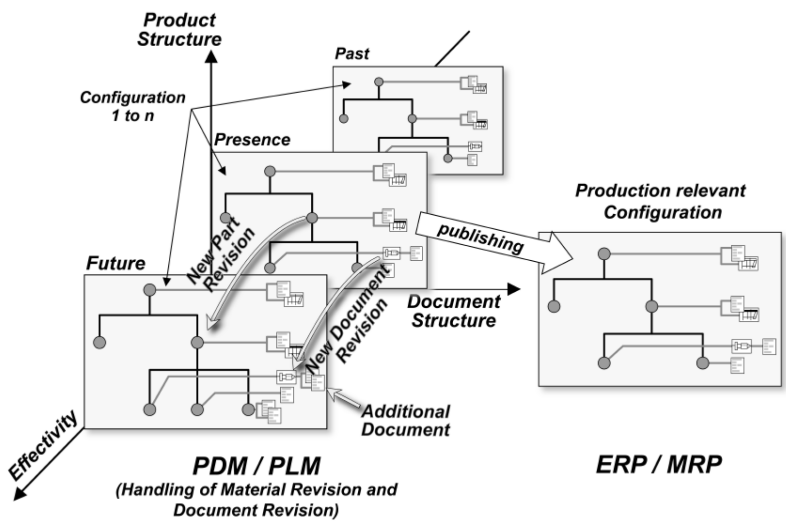

Figure 4 Configuration management and interaction with the PPS System.

According to these standards, CM is a management discipline that is used across the complete lifecycle of a product in order to ensure the transparency and control of its functional and physical characteristics.

Past configurations represent all designed and/or manufactured versions. The present configuration is the version of the product that is presently in production. It is typically managed in a PPS system driving the Supply Chain and/or Manufacturing/Assembly. Future configurations are product and document structures that are presently undergoing a change, but are not yet released for production (Figure 4).

In addition, a product configuration is also determined by customer-specific choices from several variants or alternatives.

3 What are the trends in Configuration Management across industries?

Analyzing the state-of-the-art it is evident that most organizations have a long way to go if they want to introduce a comprehensive and integrated CM solution. The main task in the definition of a configuration management process is to select a sensible and manageable quantity of Configured Items and to reduce the number of systems employed in the process. The key objectives for the selection are:

- The integration across the product life cycle,
- The integration across the different disciplines, and
- The integration of the Supply Chain.

For the integration of the product lifecycle from a contemporary state-of-the-art, the components of the engineering and manufacturing BOM have to be defined as CI. It is, however, problematic that the two BOMs typically are managed in different IT systems. More forward-looking projects in the industry integrate the requirement was well functional structures into the process. The integration of the disciplines can be located on a similar level. According to the key competence of an individual enterprise, the focal emphasis of a CM solution will be placed on the respective discipline.

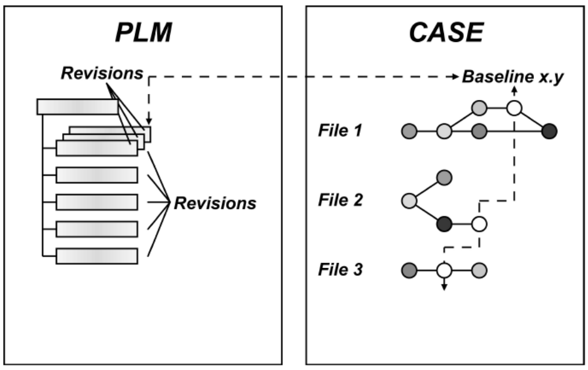

Figure 5 Integration of Case Tools and PLM Backbone.

In today's Automotive and Aerospace industries, it is common to define mechanical and electrical/electronic components as CI's. However, in many cases, they are managed in different systems. Software is typically created in CASE tools and revisioned independently. While mechanical and electrical/electronic components can be represented within the existing structures of a PLM environment, the management of software builds is more complex. On the one hand, the frequency of changes is higher by orders of magnitude, and, on the other hand, the CASE tools have change mechanisms of their own to manage revisions, baselines and configurations. A method of integrating CASE tools and PLM environments is represented in Figure 5.

The integration of the supply chain is also not fully implemented. The High Tech industry is leading the way, as it has defined PDX standards to integrate suppliers within its standardization organization. Similar approaches are pursued by the VDA automotive manufacturers' association in Germany. The objective of these initiatives is to harmonize change processes between project partners and to minimize the costs related to the implementation of change requests. An additional aspect of Configuration Management is represented by the problems related to managing variants. Products are comprised of Martin Eigner, Aline Fehrenz several variants on a parts and assembly level. The management of variants is of cardinal importance for the Purchasing Department, as the number of potential product variants can be extremely high. For an exemplary representation of variant complexity, we will take a look at the front seat of a passenger car. The influencing categories are represented in Figure 6, together with their respective specifications.

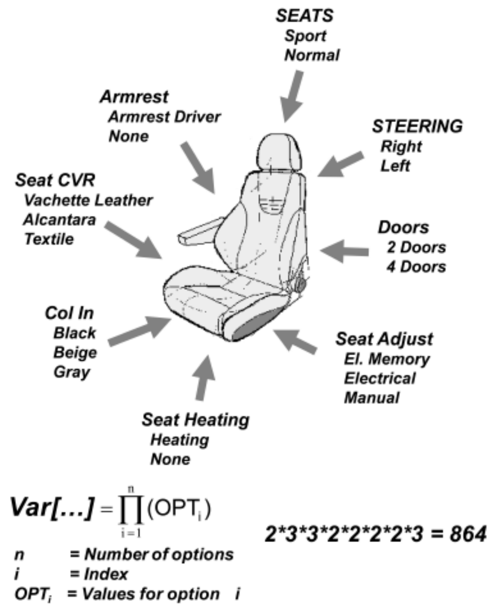

Figure 6 Example of an auto seat variant [6].

With unrestricted combinations (i.e. assuming that no manufacturability rules have to be considered), the specification categories lead to the following number of variants: 2 * 2 * 2 * 3 * 2 * 3 * 2 * 3 = 864.

Traceability of product variants delivered to the customer, in conjunction with the revisions created in the change process, are also part of configuration management. In the case of a failure of a passenger vehicle, it is necessary to show the selected revisions for each variant of the seat.

4 What are the top considerations for CM implementation?

It is quite evident that CM builds on a consolidated representation of product structures. Main elements are therefore also requirements for an implementation are:

Linking of lifecycles via associated product structures,

Derivation of view for different applications.

Associativity of product structures means the linking of different product structures across the phases of a product lifecycle. Figure 7 confronts a theoretical solution with today's industry reality with the management of product structures in disconnected IT systems.

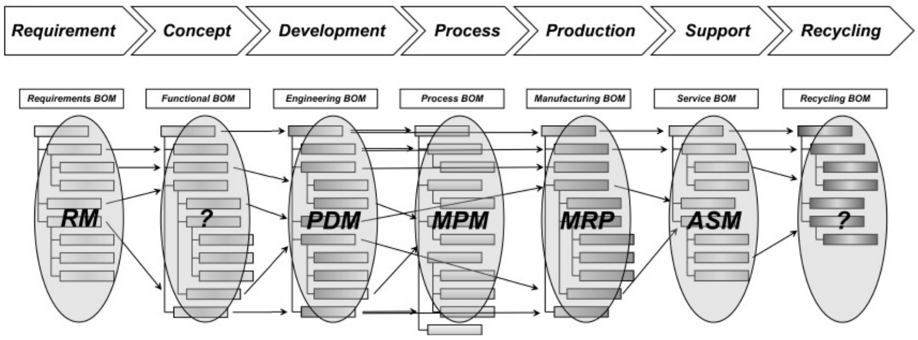

Figure 7 Associative product structures.

In most cases, the different product structures are managed in disconnected legacy systems, such as RM (requirements management), PDM (product data management), MPM (Manufacturing Process Management), MRP (Material Resource Planning) and ASM (After Sales Management), or they are not represented at all, just as functional product structures are not used. If software and electronics prevail in a product portfolio, it is quite common that solutions for Systems Engineering (SE) and non-hierarchical product structures are used for the initial phase of requirements and concept. An example would be model descriptions based on SysML, Modelica or similar authoring tools (Figure 8). But this approach typically does not comprise an integration of early product development phases with the eBOM.

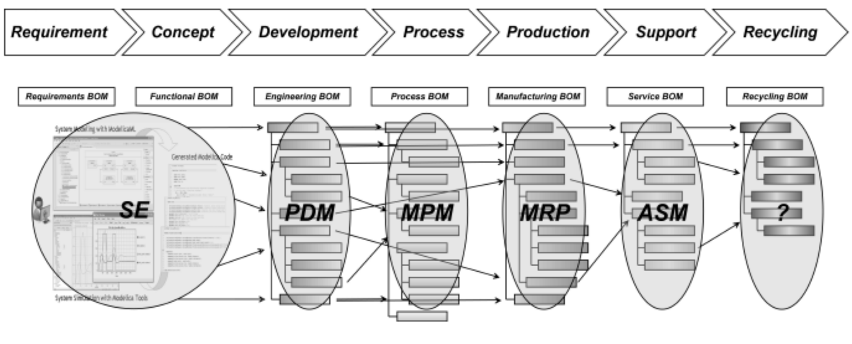

Figure 8 Mixture of Systems Engineering approaches and conventional product structures in High tech industry.

Modern PLM approaches are capable of managing product structures starting from the requirements down to the processes, both in a hierarchical and in a network-based approach, within a consistent and common data base. This framework provides the foundation to enable associative product structures in a “creating” and in an “executing” system environment. The prerequisite for this approach is an intelligent coupling of PLM and MRP. Based on a networking of information through associative product structures – or through intelligently integrated legacy systems – and through a skilful assignment of attributes, the users are able to generate different views (Figure 9).

Both associativity and generation of different views supports the concept of a „single source of truth“, which is an indispensible prerequisite for any approach to configuration management across the product lifecycle. To enable decisions for dependent consequent changes, any change of a product and production -relevant information must therefore have visibility into all related information across the complete life-cycle.

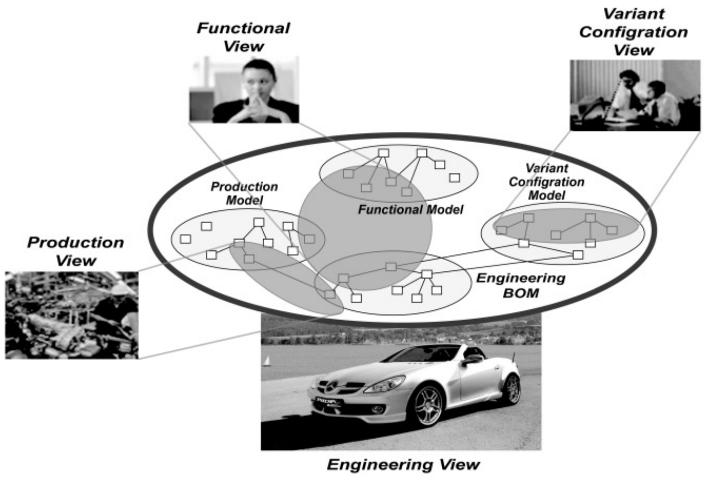

Figure 9 Derivation of views from associative product structures.

To realize these requirements it is also necessary to have a look to the PLM architecture. The main difficulty associated with today’s architecture lies in the coordination of information items and processes between the PLM-defined Design Chain and the MRPdefined Supply Chain. The difficulty is aggravated by the fact that MRP systems typically do not have the freedom to adapt or customize both product and process models. Therefore, in many cases, a common process definition is based on the least common denominator. Frequently, a revisioning of product master data sets in MRP is only viable via the associated documents. In particular, in some leading organizations, the latter issue leads to a discussion around an integrated architecture that builds on a common backbone for product structure, ECM and CM, both for the design chain and the supply chain. In this approach, the different, instantiated MRP systems are reduced to mere execution systems that pull their information from the common backbone (Figure 10).

The justification of the above solution lies in a comprehensive support of the vision of a single source of truth through a common database, as well as in the performance and flexibility of PLM systems that are capable of covering the growing complexity of today's products and processes.

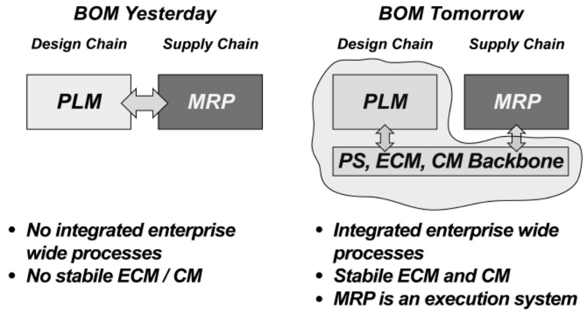

Figure 10 Modern architecture for a common PS, ECM and CM backbone.

5 How does Configuration Management drive business value?

In any fast moving business agility is a significant contribution to business success. Agility requires a high degree of process efficiency: quick response to new and changing requirements of the customer and the resulting changes in the products and means of production is an essential quality feature of any business. CM is a core process of a company whose job it is to implement and monitor the changes of customers, suppliers and other engineering stakeholders on all disciplines, internal and external organizational units within the supply chain these process starts from requirement, styling, and engineering till process planning, manufacturing, operating and recycling. Thus CM assures the consistency of each product or service in terms of requirements, functional and physical characteristics, design and documentation. This builds on a well-functioning product and process management. The Aberdeen Group shows that quality, time to market and costs, the main reasons for the optimization of the CM in the company are (Figure 11). The costs include influencing the entire life cycle costs and thus directly to the company's profits. This makes CM a key driver of a company's profitability [1].

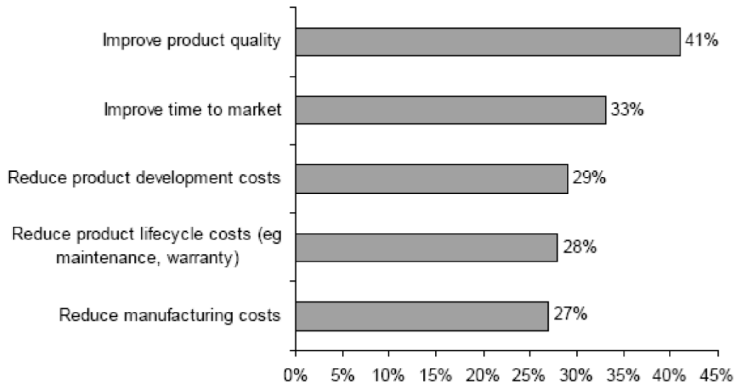

Figure 11 Pressures Driving Improvements in Configuration Management (Source Aberdeen Group 2007) [1]

Therefore it becomes clear that CM has a significant impact on the profitability of a product throughout its life cycle. Based on Aberdeen Group, however, a number of challenges have to be solved technical and organizational before CM can be implemented in a company successfully:

- Maintaining accuracy of BOMs,
- Management of engineering changes across configurations,
- Keeping down-stream BOMs in sync with engineering changes and,
- Managing BOMs and engineering changes across variant configurations [1].

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Chapter 8
PLM Semantics

Complete Material Information during the Product Life Cycle

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Abstract: This article will analyze the challenge of handling material information from different sources and different phases in the product life cycle. The needs for various kinds of material information are analyzed by different subjects (legislative regulations, construction design, strategically requirements). The information sources are examined in order to understand the differences and reasons for the difficulties that occur when integrating the material information into the systems. As a result the main problem will be identified: the appearance of different semantics in the material naming. Two possible solutions to overcome the difficulties and to make the available information accessible are evaluated and compared. These approaches are a data warehouse and an intelligent search engine. On the basis of the evaluation the search engine approach will be identified as the preferred one.

Keyword: Semantic problems, Material information, heterogeneous systems

1 Introduction

During the phases of the product life cycle various kinds of material information is needed. An extract of the different information groups are shown in figure 1. These groups of material information are used in different departments and phases of the product life cycle. The information of the groups is spread in numerous heterogeneous information sources (systems, data bases, documents, etc.).

The information landscapes of companies (especially bigger and older companies) have developed over time which is the main reason for the heterogeneity. One characteristic of such heterogeneous environments is that the different sources are sometimes not connected to the main product data management systems. As a result only the master data (like part number, naming, etc.) of parts is lined up between all of the systems. In consequence the probability of semantic differences between the sources is very high and has been observed several times when it comes down to more specific information.

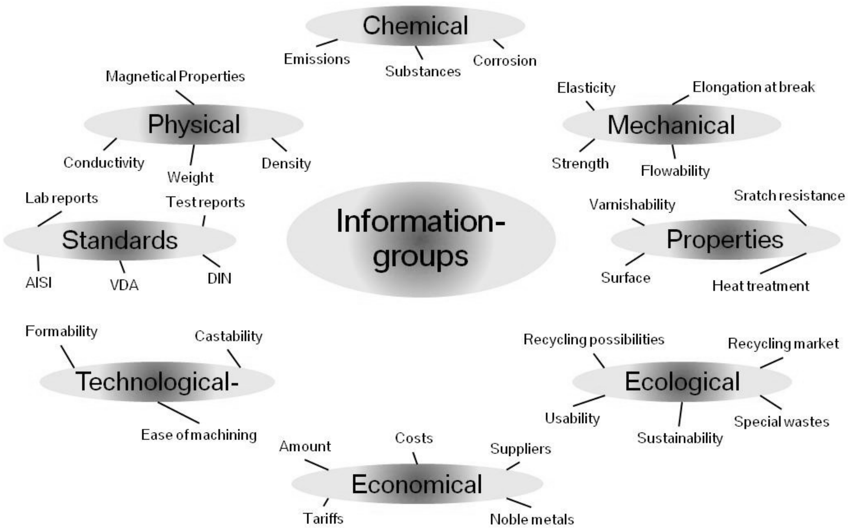

Figure 1 Groups of material information (examples)

Concentrating on the material information it has to be mentioned that the material specifications like naming or certain properties are not part of the master data. So the semantic differences have a significantly higher impact. Especially the naming of the materials is affected by semantic differences, as a result of the big number of data supplier. Material information is gathered from a lot of different sources along the supply chain and various external and internal sources during the product life cycle. Dealing with such a big variety of sources the appearance of semantic differences can't be avoided completely.

Because of the stated fact, even seemingly simple reports regarding material information fail. For example the question how much of the steel "DC01" is used in one car or in average in a construction group is hard to answer because there are more names for the desired steel, e.g. "St 2" or even names like "Carbon steel" or "Unalloyed steel".

2 Examples for information needs

The reasons for the need of new and completely integrated material information is divided in two different origins: One reason is the obligation to be able to report detailed material information by law, the other reason is the requirement of the development process, also influenced by newer strategically motivated reports and technologies.

Integrated material information means in this case that the material information of the various sources are matching and complementing each other. That consists the same naming in the different sources opening the ability to analyze the material information from different sources automatically.

2.1 Development process

In the “traditional” fields of product development the following standard set of material information is needed:

- Design: Designing the parts with individual materials to make sure, that all requests (stability, design aspects, weight, etc.) to this part are fulfilled.
- Simulation (finite element analysis): Verifying the chosen materials in an early phase of the development process regarding strength and durability.
- Compliance: Information for proper documentation (tests, naming, assembly instructions, etc.) of the chosen materials.

Construction and simulation data is punctually needed during the development phase. In regards to compliance it is important that all the information leading to the choice of a certain material is available for a long time period. In case of functional failure in a part the manufacturer has to proof that he did everything possible to exclude the material or design as cause of the failure.

Additionally there are more and more new fields in the development process that need a very specific set of material information. These fields are for example:

- E-mobility
- Using innovative materials as carbon fiber for lightweight construction.
- Environmental lifetime assessments

Because of the above shown complexity in these individual topics, there are several departments involved, including one department specialized in the material information.

2.2 Regulations by law

Regarding the automotive industry in Europe, there are two important regulations (2000/53/EG and 2005/64/EG) by the European Union [7,8]. These regulations require two reports: the material composition in seven categories (metal, polymers, rubber, modified organic natural materials, glass, liquids, other) to guarantee the recycling quotes (reuse and recovery has to be at least 95 % and the reuse and recycling has to be at least 85 % of the vehicle weight [8]) and the compliance with the prohibited materials. This information has to be presented along with the start of the production and is a requirement for the type approval. To fit these requirements the material information has to include the chemical composition of every part build in the sold cars. Currently the four substances Chromium(VI), Cadmium, Lead and Mercury are prohibited in the regulation 2000/53/EG..

There is an emerging field that requires completely integrated but still very specific material information. This field is the REACh (Registration, Evaluation, Authorization and Restriction of Chemicals) legislative. REACh needs the chemical composition for every single produced part and sold article. The major difference to the prohibited substances by 2000/53/EG is that potentially the usage of every substance can be restricted by REACh [11]. As a result the monitoring of the used substances is not restricted to the individual components of the product but affects everything that is sold by the company. The new challenge coming up with REACh for a vehicle manufacturer is the fact that also the accessories and merchandising articles have to be monitored. So the amount of material information is increased significantly as does the number of suppliers providing material information.

The EU is not the only market with regulations like the above mentioned ones. There are more and more markets with similar laws (e.g. Japan, Korea, China). Considering the complex requirements by law, the need for integrated material information gets crucial. If the legislative requirements can't be satisfied the consequences will be significant. It can be high fines or even the denial of a type approval.

3 Data sources

3.1 Groups of possible information

The material information needed to fit the information requirements mentioned in chapter 2 is stored in different sources. In order to analyze the possible sources, they were assigned to four different groups.

3.1.1 PDM systems

The first group is the product-data-management (PDM) systems. These systems are used to handle the master data of the parts. In contradiction to the two other groups, the main PDM systems within the examined environment are connected. The system landscape consists of the main ERP based systems and some other (mostly older) systems based on other platforms. These systems are integrated in the system landscape of the PDM, to make sure that the master data (like part number, naming, etc.) for each part is consistent. So most of the systems are connected, but only a small part of the contained information is integrated. Because the material data isn't part of the master data yet, this information is not consistently displayed within the already connected systems.

3.1.2 Information provided by supplier

Focusing on the internal information handling is not sufficient, because often the cooperation with suppliers starts in the early phases of the product development. So the second group of material information is the information provided by suppliers. As described in chapter one, if the supplier takes the responsibility for development process, the information (all but the master data) is stored and designed fitting the supplier's systems. In these cases the information (including the material information) is transferred at the end of the development process with the rest of the documentation. This kind of formalization may cause inconsistent material information.

To exchange detailed material information (chemical composition) between the OEM's and the suppliers a standard platform to transfer the information was developed within the German automotive industry and is now used worldwide. This platform is the IMDS (International Material Data System). The IMDS is a web based program in which material information can be uploaded and published to a list of recipients. In that way the supplier can give the information regarding a part that is bought by several customers to all customers at once [12]. Because most of the suppliers work for more than one OEM they don't use the OEM specific semantic or material naming, they use their own.

3.1.3 Unstructured information

The third group of sources for material information is unstructured information located on the different file servers, the internet or the local hard drive. Unstructured information is information that is not stored in a strict or fixed structure like a database or some sort of system. Through surveying employees working in different functions along the development process it became apparent that these unsorted files are a very important knowledge source regarding material information, especially in the early stages of the development process [3]. Locating this information is very difficult, because the search possibilities are very limited. You have to know at least approximately where you have to look for the information and you have to know the exact phrases to use to find the desired information. Thinking of the semantic differences, it is obvious that the present situation is not satisfying and should be improved [3,5].

3.1.4 Information in software tools

The last category of sources for material information consists of the databases that are part of a software tool. Especially calculation and simulation programs are often equipped with their own set of material information. Because of the origin of the data (the software supplier), the possible semantic differences to the other systems seem to be quite obvious. Another difference to the other groups to be thought of is that this data is not connected to the system landscape of the company. Even if technically possible the company wide usage of this information has to be checked with the software supplier. It may be necessary to change the license agreement, which can possibly be very expensive.

3.2 Evolving new sources

With the new requirements for material information the need for new systems and tools for data acquisition and administration arises. Analyzing the used PDM-systems in use it was recognized, that the main PDM system is based on ERP. Nevertheless there is a certain amount of systems developed independently from the used ERP because of different reasons.

One example is the MDS System (Material Data Sheet System) which is the company's in-house-tool for handling the IMDS data. At the beginning it was developed to monitor the material data sheets for the parts delivered by suppliers as part of the initial sample inspection. But nowadays it is one of the most important tools regarding material information for reports requested by laws. When the tasks of the system were expanded, it was thought of integrating the MDS in the PDM landscape by integrating it in the ERP PDM system. The decision to use Oracle further on as the system platform was first of all made by the higher flexibility to customize the tool easily [6].

Another reason for creating a new system to gather certain data is posed through legislative or intra organizational requirements. There are certain types of information that have to be separated from the rest of the systems and where the access is only granted selected employees. Cost information for example must not be published in the company, because this information is highly confidential since they contain sensitive information of the suppliers like hourly rates and other internal costing information. Software licenses are another reason to separate respectively not integrate information. Not every software program can be used in the whole company, because a lot of software is licensed for only a handful of users. So the information contained in that software has to be constricted to the actual users.

4 Data quality and diversity

The stated facts concerning the information sources influence the data quality. Because the diverse systems developed over time and out of individual motivations, the stored information is independent (except the master data, see chapter 3.1.). This is one main reason for the occurrence of semantic differences regarding the material information between the systems [4]. These differences are in most cases different labeling systems so that an automatic comparison between sources is not possible. Sometimes the same terms have different meanings for certain departments, e.g. development and purchasing departments.

The stated semantic differences between the systems are responsible for the difficulties to join the information of the sources. Manually, quite often there is no problem recognized, because the users working with the information are capable of distinguishing the differences in the used semantics, sometimes even without recognizing. Even if the users don't recognize the semantic differences, they have to search in each system respectively each information source separately. That has some disadvantages: first of all it is very time consuming [9] to get more than one kind of information for a certain material. Another point is that you have to compare the different information manually to make sure that there are no inconsistencies or misunderstandings because of semantic differences.

For integrating the different sources the semantic differences are very problematic and until now there is no general solution [4]. Also it may happen that the information in one single system does not follow the same semantic rules. For example the IMDS: because every supplier and OEM creates their own data, using their own, internal rules, names and notations, there are a lot of different semantics in this one information source. So if this information is supposed to be used to create a consistent information set, it has to be done manually. This problem was recognized when trying to use the IMDS data to do certain analyzes concerning prohibited materials. Because of semantic differences it was impossible to order and group the material data by the given material name. It is possible to analyze the data by the VDA classification [6].

The various origin sources can be external or internal. External sources are for example standards like ISO or AISI describing the requirements to the individual materials. Possible internal sources can be records from test plants or expert knowledge.

Especially the problem of using different semantics in different information sources has been observed repeatedly [2, 4]. Nevertheless the employees working with different tools and systems should be able to compare the tool internal material data with the company wide used material data to avoid the possibility of misunderstandings and to focus on extending the tool's material information via one central department.

5 The solution: Data Warehouse vs. Search Engine

Two possible answers to the question, how to manage all these different material information out of all are generating a "master-database", e.g. a data warehouse, or generating a possibility to look into all the sources with one central search engine.

5.1 Data Warehouse

A very obvious way to solve the problem is to build a classical data warehouse, which is connected to the different sources. The data warehouse is based on the idea to collect specific information from different systems and to store this information in a structure that makes the evaluation of the data more effective. Regularly new information is generated by combining the different sources. The collection of the data is done by a script searching the different sources on the basis of defined and static rules [1].

Thinking of the different systems containing material information, this solution seems to be very practicable and solid. Under certain circumstances, it appears to be the most suitable approach to this problem. The advantages of the data warehouse can be summarized as follows:

- Consistent and valid rules to merge the data of different sources.
- Possibility to analyze the data in various ways.
- Very good system performance.
- Easy to apply security requirements in regards of information security.

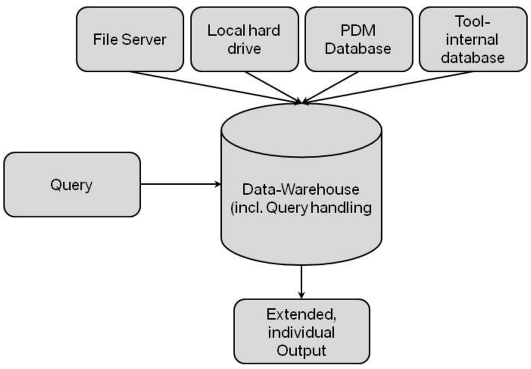

Figure 2 Possible structure of a data warehouse solution

The underlying structure of the data warehouse solution is shown in figure 2. Three of the mentioned information sources (see chapter 3.1.) can be implemented in the data warehouse easily. Local hard drives and internet sources are problematic to implement in a data warehouse structure for different reasons: The internet is for example subject to constant changes and has no strict structures like databases what makes it difficult to get the important information using a static script. The local hard drives shouldn't be scanned during the working hours, because that would cause a dramatic performance problem on the client computers. Running the scan over night would not be useful, because the client computer won't be running or connected to the company network.

The disadvantages of the data warehouse solution are not immediately apparent. But depending on the main targets to be covered, there are some points that have to be thought of. Problems are especially posed through having to copy the data to build up a data warehouse:

1. A significant amount of additional data is generated. Thinking of the costs generated by the needed storage and software it can be questioned, if the additional value is higher than the additional costs. The main cost factors are the storage itself (hardware) and the software on top (database, etc.).
2. The process of copying the data itself generates a huge amount of traffic in the company network and therefore needs a lot of time. Thinking of the high frequency of changes in the data, the stored data would always be behind. Constantly working with data that is not updated is crucially impacting the development process and is therefore not a feasible solution for this kind of processes.
3. It should be mentioned that integrating new data sources is quite complex. The mapping between the new data source and the structure of the data warehouse can be problematic, if the information structure of the new source is significantly different to the previous ones.
4. Because the data warehouse is a database, it makes all of the administrative work necessary, in addition to the existing administration for the existing systems.

5.2 Search Engine

The second alternative is to create a central tool that is capable of getting real time information from the different sources (systems, databases and file servers). This central tool can be a search engine that is connected to the different sources. Because of the direct connection to the different sources, there is no need to copy the data, which at the same time reduces the necessary administration significantly. The second significant advantage is the possibility to work almost in real time on the sources. All this significantly reduces the possible costs to run such a system.

Because one key request to the system is the capability to deal with the different semantics, a standard search engine by itself will not be sufficient. Therefore the search engines need to be combined with some sort of "translator"-tool that is able to translate between the different semantics. The idea is, that the user that is searching a certain material gets all the information, also for all possible synonyms for the given name of the material (see figure 2). So the favored solution is a hybrid between a classical search engine and data processing to overcome the semantic issue.

As shown in figure 3, the query given by the user will be extended, e.g. with all the known synonyms. Also the consolidated output is handled by the background database. This possibly enables the system to filter the results and to normalize all the results to one semantic (regarding the material name). Also the search results can be filtered in respect to the user's rights for the implemented systems. That is essential to fit the requirements regarding the information security.

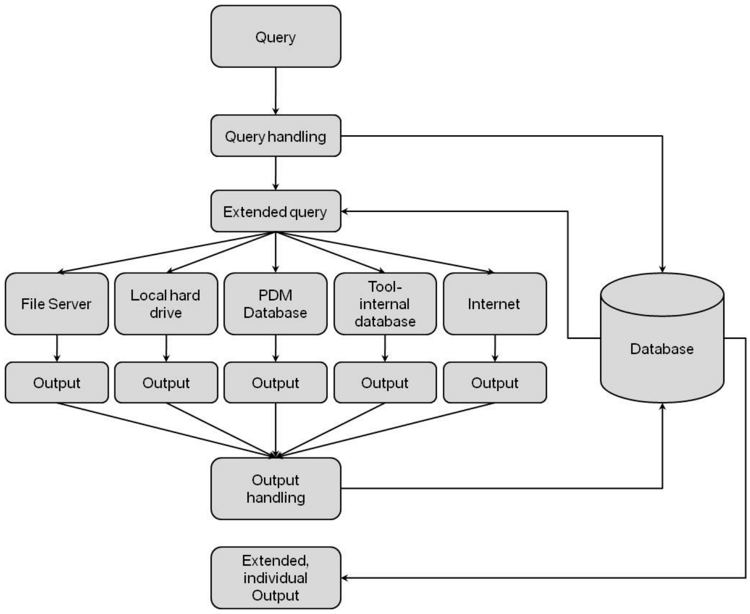

Figure 3 Possible general structure for the future tool

The challenge that is posed to this solution is to overcome the different used semantics. As argued before, there is no general solution for overcoming the semantic problems until now. So the future work in this project will focus on possible ways to overcome the semantic differences regarding the different naming for materials.

6 Recommendation Search Engine

After comparing the two possible solutions, the search engine appears to be the more sufficient approach. Especially the high flexibility in combination with the comparatively low administrative effort needed led to the recommendation. The integration of new sources can be done independently from the already integrated sources. This flexibility is very useful if internet and unstructured sources are supposed to be integrated as well. Both of these sources are dynamic and not as static as data bases or information systems.

Another important advantage of the search engine is the ability to find and handle information more effectively using all the functions a search engine provides. This is based on the matter of fact that the search engine is searching in the actual systems and sources and not a summarized copy of the data.

7 Conclusion and next steps

The challenge of combining the material information of different sources in different departments in a company is complex and because of the mentioned effects (e.g. information not integrated between systems) and needs (e.g. legislative requirements) quite important to master. Thereby there are two problems arising to master that challenge: First is the connection of the systems and sources itself and publish the information via one defined way. The second problem is the occurrence of the semantic differences in the material information between the different sources which makes an automatic combining of the sources impossible.

Of the two approaches to overcome the first problem the search engine is recommended. The main advantages over the data warehouse are the higher flexibility and the possibility to implement unstructured information sources like file servers or internet sources as well. By combining the search engine with a data base, functions like filtering the search results to the individual rights of the current user are possible. Using this approach it is possible to get material information from different sources with one central tool. The remaining challenge is overcoming the different semantics.

Future work should concentrate on two main topics: In order to be able to overcome the semantic differences in more than one system, the development of a translator tool (based on the chemical fingerprint and/or physical and mechanical information) has to be finished. The second topic is the data security. When also sources are connected, that contain confidential data, the security of this information has to be assured, ideally without restricting the benefits of the system.

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The Cone-BOM model for consistent and minimal product structure representation

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Abstract: The lack of interoperability between information systems that support design and manufacturing is still known as one of the major open issues in the eld of Product Lifecycle Management. Especially, the BOM transfer between PDM and ERP su ers from a lack of consistent model that would enable a conservative propagation of updated information from one system to the other. This paper introduces a minimal model, based upon an ontological description, that aims at linking, in a consistent manner, design and manufacturing views. This model can be represented in a graphical way, using a cone topology to extend the semantics of the dependency links, leading to the so-called Cone-BOM model.

Keywords: interoperability; Engineering Bill Of Material (EBOM); Manufacturing Bill Of Material (MBOM); ontology; Description Logic (DL); Semantic Web Rule Language (SWRL).

1 INTRODUCTION

Product Lifecycle Management (PLM) is usually presented as a cross-cutting activity that goes from the design to the maintenance and finally to the product recycling phase [1]. Moreover, the strategic purpose of the PLM activities is to control the complexity of the dynamic system composed of a high number of interacting subsystems like suppliers, customers, employees, factories or heterogeneous information systems involved in the product development [2]. The latter plays a crucial role, since IT systems enable sharing/exchanging/distributing the product related information across the whole enterprise. According to the Metclaf's law, "the value of a network increases exponentially with the number of nodes (participants)" [3] under the condition that the level of interoperability increases at the same time. Interoperability is defined here as \the ability of two systems (or more) to communicate, cooperate and exchange services and data, thus despite the differences in languages, implementations, executive environments and abstraction models" [4]. Interoperability then appears as a major issue in a successful PLM deployment strategy. It is well known so far in the literature that this issue is still widely open, and that the lack of interoperability has to be overcome [5].

According to [6], interoperability must be achieved at three different levels: the technical, semantic and organizational levels. The semantic level, which addresses the meaning of the data, is the focus of the present paper: this research deals with the way to preserve the semantic flow from any information loss during data transfer between design and production information systems, such as Product Data Management (PDM) and Enterprise Resource Planning (ERP) systems. Indeed, Ben Kheder et al. [7] state that "the main need today [in the production information systems] is the communication of updated data from engineering to production management".

The EBOM/MBOM consistency issue in a sharing/exchange purpose is the intent of this study. The paper is then structured as follows: section 2 introduces a state-of-the-art related to product models and their limitations and shows the contribution of ontologies in a federative approach of interoperability. Section 3 proposes a new minimal product model, based upon an ontological description, suitable for the design/manufacturing interface interoperability. This model is illustrated on a study case in section 4, whereas section 5 discusses this model. Finally, section 6 concludes this paper and introduces further works.

Since PLM systems are very large and complex organizational systems, planning for change in these systems is essential. It

2 Product modeling at the design/production interface

The semantic interoperability can be achieved from several approaches [8]: integration (all the participants must use a shared data standard), unification (establishment of mapping rules between participants) and federation (dynamic collaboration of different participants). Many recent works dealt with the unification approach [9] [10] [11] for the semantic interoperability, which is known to be more agile and flexible than the integration one. Authors use either *ad hoc* data models or standard data models to perform data mappings that support information flow. Product data models used for the unification provide a *static* description of product structures [12]. Additionally, the mappings are built manually, thus leading to static mapping tables, that are not totally compliant with highly agile and flexible solutions. The federative approach, based upon ontologies and reasoning, then seems interesting to overcome this limitation.

According to [13], ontologies are a “formal, explicit specification of a shared conceptualization". As [14] explained, “a conceptualization is the extraction of vocabularies from a domain and is an abstract, simplified view of the world that we wish to represent". There are two common languages to describe an ontology: RDF graphs and OWL [15].

Ontologies are a relevant tool for working on a federative approach. Recently, several works in the PLM field are using ontologies [16], like the Open Assembly Model (OAM) and the models developed by Lee, Brandt and Zhang concerning respectively the Beginning Of Life, design knowledge management and design environment. Ontologies can be extended with *rules* that constraint the model. According to Fiorentini [17], “OWL-DL/SWRL is the only approach [to integrating ontology and rules] that has been applied in product development". DLs are a family of logic-based knowledge representation formalisms creating an object oriented model whereas SWRL is a language for editing domain specific rules, that completes the expressiveness of the OWL-DL language [18]. According to the literature review, following choices were made for the model we aim to build: a simple and dynamic data model, intended to product structures exchange, has to be designed using ontologies and rules in order to perform reasoning and infer suitable mappings between information. The next section introduces this model.

3 A minimal product model based upon ontologies

The proposed conceptualization aims at extracting semantics from the local (design and manufacturing in this case) views and to implement them in a higher level minimal model, based on the use of ontologies. Then, by reasoning on the model, it is possible to extract inferred data and to recite them into the local views. Through this way, the mapping between design and manufacturing element is indirectly but completely achieved. The following subsections present classes, properties and restrictions of this ontology.

3.1 EBOM/MBOM similarities and differences analysis

Although the engineering and manufacturing BOM share a common representation (i.e. a tree-like structure), they deal with very different meanings: the EBOM defines the virtual product whereas MBOM describes a process view enabling the Material Requirement Planning [19] required for the manufacturing stage. The first step of the modeling process is to figure out similarities (and differences) between EBOM and MBOM:

- they both present a tree structure composed of nodes (items) and parent/child relationships. These relationships hold a large amount of semantics, but mostly in an implicit way [20],
- the nodes refer to items of different nature. EBOM items may not be present in the MBOM and *vice versa*. However, they seek to a specific meaning for the designer or manufacturer. As a consequence, all items have the same existing need and will be treated in the same way in the proposed model,
- in both BOMs, the parent/child dependency links express a composition link. The parent is indeed not a new or separated element, but the addition (or union) of all its children,
- in both BOMs, it is possible to make an explicit *contact* link between the children. If the link between two children is not constant over the time, there does exist indeed a contact loop between all the children. This contact link will be the model for interactions between both BOMs.

The previous points drive the construction of the ontology: following subsections describe classes, properties, restrictions and domain specific rules of this ontology.

3.2 Description of the classes

The first class we create is the Item class. Dealing with the design/manufacturing interface implies two subclasses: `Eitem` for the EBOM entities and `Mitem` for the MBOM entities. As this ontology aims at describing the link between MBOM and EBOM, the different entities have three possible configurations:

- the `SameElement` class corresponds to the items that exist in both BOM,
- the `LinkedElement` class corresponds to the items that have a link with the other BOM,
- the `NoInterfaceElement` class corresponds to the items that refer to no one in the other BOM.

These three classes are subclasses of Interface. One of the query that the ontology will need to answer is to nd the isolated items (i.e. the item that belongs to the NoInterface class and have no children). These items have no reason to exist (the only logical NoInterface items are the phantom items or the design assembly items, that do have children) and are waiting for a *has_interface* property. The ontology needs a class to express the existence (or not) of a parent/child link between items: the Parent class. Finally, as the model aims at providing all the available information hold by the items, the SemanticInformation class is created. This class may have as many subclasses as needed, depending on the application (for instance, a material class in the steel industry, a color class in the jewelry etc.).

3.3 Description of the properties

The object properties enable to characterize and link the different classes to each other. First of all, the *has_element* property is the expression of the parent/child relation that links items in each BOM. *Has_Eelement* refers to the EBOM, as *has_Melement* refers to the MBOM. This property is a *transitive* type and has logically the reverse property *is_element*. The property *has_element* refers to the class Item. In order to link design and production entities, the *has_interface* property is created. This symmetric property expresses that an Item may have an Interface. There are two different sub properties to *has_interface*:

- if the two connected items directly correspond to one another, the is_the_same_property is used,
- if the two connected items are not exactly the same concept but in uence one another, the *is_linked_to* property is rather used.

Finally, the *has_info* property links the SemanticInformation instance to the corresponding Item instance. The data properties are various kinds of properties that add information to the individuals. These properties depend on the need of each business case, but can be as following*:*

- *has_owner* is a string property linked to the class Item and that enables to attach the name of the author to the item. *Has_owner* could be an object property in the case of the owner has to be chosen in a premade list. Thus, owner would be a subclass of SemanticInformation and *has_owner* would link Owner to Item. This observation has value for all the data properties,
- *has_reference* let to attach a reference to the Item (name of the le, URL link, etc.),
- *has_quantity* is a float property linked to the Mitem class to express the cardinality of the MBOM.

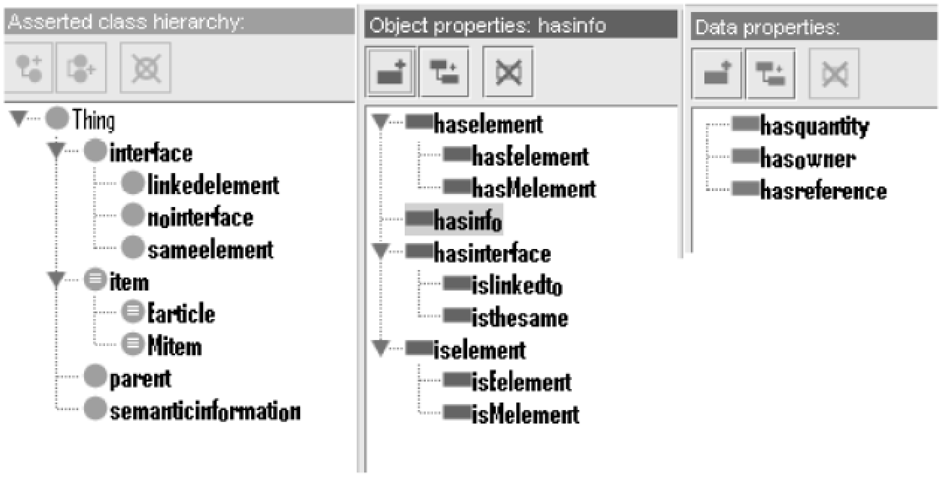

Figure 1 Classes, object properties and data properties defined in Protégé.

3.4 Restrictions

To ensure the consistency of the ontology, restrictions are added from the Protégé environment:

- `Has_element` links only two individuals of the same `Item` subclass,
- `Is_linked_to` and `is_the_same` link two individuals of different `Item` subclasses, individuals of the Item class have at most one `is_the_same` property.

3.5 Domain specific rules

The domain specific rules provide specific constraints to the ontology, that cannot be expressed in the OWL language. A way to implement SWRL language, in the Protégé e-OWL environment is to use SWRLTab, executed by Jess [17]. To complete the product modeling, the following domain specific rules are defined:

- an `Item` that has the is linked to property also belongs to the `LinkedTo` class,
- an `Item` that has the is the same property also belongs to the `SameElement` class,
- an `Item` that belongs neither to the `SameElement` nor to the `LinkedTo` classes belongs to the `NoInterface` class,
- an `Item` that has the `has_element` property belongs to the `Parent` class.

3.6 Graphical representation of the model

In order to make this model more understandable, a graphical representation is proposed (see figure 2). The discussion related to EBOM and MBOM let think that the geometrical representation of an item should have to aspects: one loop and a top. The cone topology thus appears as a relevant choice.

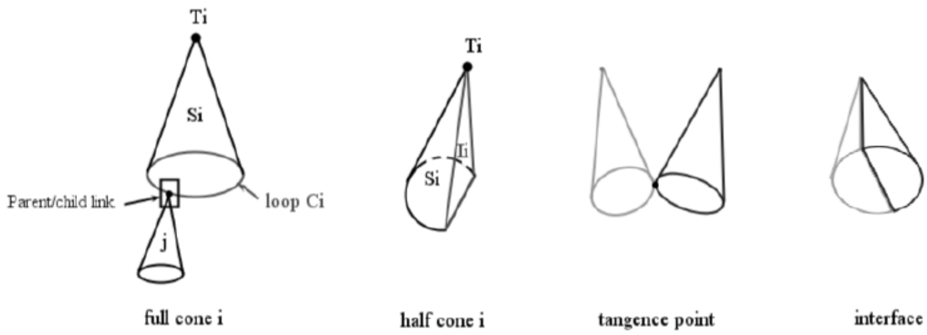

Figure 2 A graphical 3d view of the model

A cone i is composed of a top T_i , a surface S_i and a circular base C_i . The top and the surface represent the item *i*, as the loop C_i is the junction place with the children. The surface enables to store semantic information about the item. We also dene a half cone, that presents an interface surface I_i (I_i is geometrically a unfinished plan). Ii is the interface surface between the design and the manufacturing of the corresponding cones. Thanks to the reasoning over the ontology, it is possible to edit a design/manufacturing view of the assembly. The different steps to create the graphical view of the assembly from the ontology are the following:

- by submitting a query on the ontology through the reasoner it is possible to find all the individuals of a class. All the instances of the `SameElement` class are retrieved with the query
  :(retrieve (?x) (?x(or ontology.owl#SameElement))).
  A half-cone is created for each result. In the same way, a full cone is created for each element of the `LinkedTo` and `NoInterface` classes,
- the individuals of the `Eitem` class have the blue color, whereas the individuals of the `Mitem` class are green,
- for each created cone, we add geometrical constraints as following: if *i is_element* of j, then $T_i \in C_j$. For the `LinkedTo` individuals we create the tangence point $P \in C$. If I *is_linked_to* j, then $P_i = P_j$. For the `SameElement` individuals, if *i is_the_same* j, then $I_i = I_j$ and $T_i = T_j$,
- the data properties and the semantic information of each item *i* is stored on the surface S_i .

4 Study case

4.1 4.1 Description of the study case

The study case is a simplified view of a car assembly. Two possible EBOM and MBOM for this simple case are presented in figure 3.

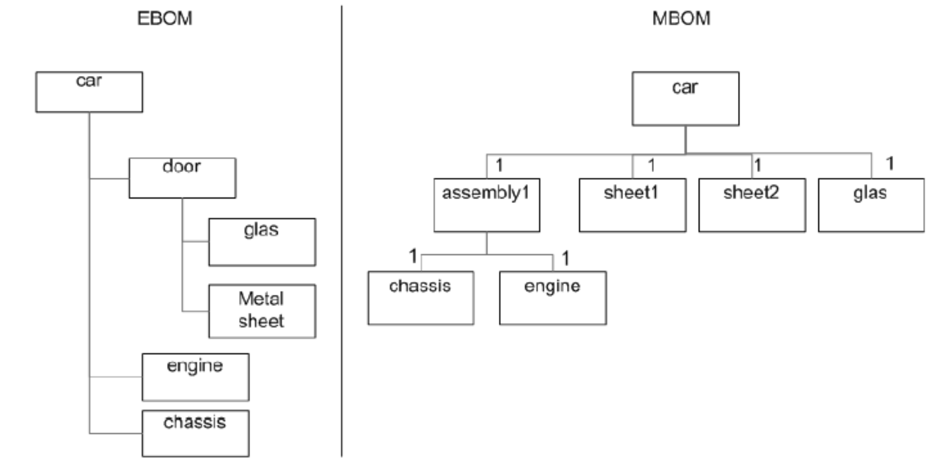

Figure 3 BOM of the study case

According to the designer viewpoint, the car is composed of an **engine**, a **door**, and a **chassis**. The **door** is itself composed of a **glas** and a **metal sheet**. For the manufacturer, the car is produced by assembling the **engine** and the **chassis** to create the item **assembly**$_1$. Then the **assembly**$_1$, the **glas** and the two **metal sheets** are assembled together. All the items of the EBOM are declared as individuals of the `Eitem` class. Similarly, all the items of the MBOM are declared as individuals of the `Mitem` class. Their names spelling start with “E" or “M".

4.2 Ontological description

The following mappings are expressed manually in the ontology:

- **Ecar** *has_Eelement* **Echassis**, **Eengine** and **Edoor**,
- **Mcar** *has_Melement* **Massembly**$_1$, **Mglas**, **Msheet2** and **Msheet1**,
- **Edoor** *has_Eelement* **Eglas** and **Emetalsheet**,
- **Massembly**$_1$ *has_Melement* **Mengine** and **Mchassis**,
- **Ecar** *is_the_same* **Mcar**,
- **Eglas** *is_the_same* **Mglas**,
- **Echassis** *is_the_same* **Mchassis**,
- Eengine *is_the_same* **Mengine**.

After a first query on the ontology, it appears that the Item **Emetalsheet**, **Msheet1**, **Msheet2, Edoor** and **Massembly**$_1$ belong to the `NoInterface` class. But among these items, only **Emetalsheet, Msheet1** and **Msheet2** are not `Parents`. The need of mapping on these items is revealed. We declare that the **Emetalsheet** *is_inked_to* the **Msheet1** and the **Msheet2**. A 3D view of this model is presented on figure 4: it should be read as a 3D extension to the usual 2D view of EBOM and MBOM as they are presented in figure 3.

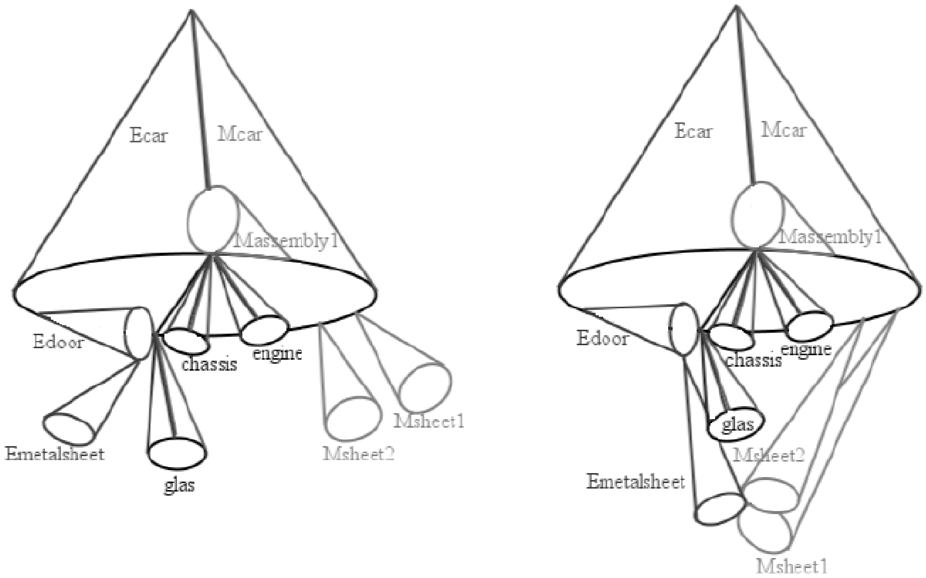

Figure 4 Graphical representation of the use case.

5 Discussion

Figure 4 illustrates on a simple case an important aspect of this model: dynamism. Unlike the current static views (EBOM/MBOM), the proposed graphical representation integrates the interface relationships by creating a model that physically evolves under some design/manufacturing constraints. The addition of the property *is_linked_to* between **Emetalsheet, Msheet1** and **Msheet2** on the left side of the figure 4 has indeed strained the right side of this figure. Regarding the data extraction, in our study case, the information of the EBOM and MBOM are obtained manually and implemented in the ontology, while it is a very simple case. In a more complex case, the information about the items could be extracted automatically from the design and manufacturing information systems. However, we think that the implementation of the different properties cannot be done automatically, as they result from a very complex and enterprise specific workflow. The goal is rather to provide tools to make these manual mapping as easy as possible for the user. In this paper, the graphical representation is obtained thanks to the ontology. However the opposite situation is possible, where the engineer is directly working on the graphic interface. By imposing geometrical constraints, he automatically instantiates individuals and properties from the ontological model. The mapping between the design and the manufacturing views that have to be manual could also be edited in a simple and visual way.

6 Conclusion

A new product model was introduced in order to make the Engineering and Manufacturing BOMs consistent. This model was so-called minimal since it was designed with the intent to enable the exchange of BOMs between PDM and ERP systems, while keeping a way to update both BOM in case of an event occur in both BOMs. This model uses an ontological representation including specific domain rules. A graphical representation of this model is presented, which is a 3D view of the items and their links, that contains all the information needed. Moreover, this model enables to express the local and specific user views, as it contains the design, manufacturing and interface information. Further works deal with the way to include a temporal (i.e. a process based) description.

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A Three-Step Approach for Structuring 3D CAD Model Comparison Scenarios

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Abstract: One aspect of PLM involves the search and reuse of products, parts and information to reduce costs and delays while lowering risks. Since 3D CAD tools and models have become prevalent in the mechanical product lifecycle, using 3D CAD models as a key to searching and comparing objects from the PLM vault is a promising avenue, and numerous scenarios will benefit from such a capability. For instance, comparing 3D CAD models of mechanical components to assess their relative shape difference leads to benefits in areas such as design reuse, sourcing, engineering change management and data interoperability. Fundamentally, depending on the scenario, the function of the comparison will vary: engineering change management entails documenting the differences, while data sharing implies ensuring equivalency. Hence, this paper presents a three-step approach for structuring 3D CAD model comparison scenarios and analyzing the characteristics that are pivotal to the selection or the design of an appropriate solution approach. The goal is to ultimately represent a scenario's defining factors through the use of a meta-model designated here as PDMF4C. As an illustrative example, this paper details the use of the proposed approach to describe the recognizable 3D CAD model comparison scenario of design reuse via shape-based retrieval.

Keyword: Computer-aided design, Model comparison, Similarity/Difference, Shape-based retrieval, Product information reuse

1 Introduction

In the present state of market globalization, product data authors and product data consumers face the challenges of collaborative and integrated product development. Today's PLM solutions need to manage, store and distribute the definition of a product, as 3D data is being shared and used more frequently and intensively than ever before. For example, 3D CAD models are increasingly used as inputs to retrieve and compare products, parts and related information from PLM vaults to ultimately enable product data reuse. Innovative PLM supports for the creation, editing, exchange and manipulation of 3D data are increasingly relied upon to stimulate fast and reliable decision making throughout a product's lifecycle.

A comprehensive survey of 3D CAD model comparison scenarios was completed as part of a broader project on the problem of engineering change transposition between differently formatted 3D CAD models. It revealed that the generic process of comparing 3D CAD models can bring a variety of benefits to multiple scenarios in the development of mechanical products such as design reuse, sourcing, engineering change management and data interoperability. However, a concurrent survey on 3D CAD model comparison methods and available tools revealed that, whereas some specific scenarios such as the validation of translated 3D CAD data have been addressed with purpose-built tools (e.g. [1-3]), appropriate solutions for many of the surveyed scenarios are still to be achieved.

Moreover, the heterogeneity of 3D CAD model comparison scenarios have led to the development of methods and tools addressing very specific subsets of scenarios sharing common distinctive traits. Such defining factors need to be systematically identified and organized prior to one's decision to opt for one of the existing solutions or, ultimately, to develop a custom-built comparison tool.

This paper presents a three-step approach designed to provide a structured representation of a scenario's defining factors: (1) the basic function of the comparison, (2) the compared models' respective forms, contents and relationships, and (3) the inquiring/inquired engineering processes. Accordingly, this approach relies on the proposed Product-Definition-Model-Formalism for Comparison (PDMF4C) meta-model. Inspired by Caplat's theory on generic meta-modeling [4], it is intended to capture the set of concepts, characteristics and links that characterizes a 3D CAD model comparison scenario. This approach could benefit, for example, engineering managers planning the migration of 3D CAD data or promoting design reuse within their organizations.

This paper is organized as follows. Section 2 categorizes different 3D CAD model comparison scenarios that have already been described and/or addressed. Section 3 introduces the proposed structuring approach and related PDMF4C meta-model by describing a comparison scenario's three defining factors. Finally, section 4 exemplifies the use of the proposed meta-model on the typical 3D CAD model comparison scenario of design reuse and on the corresponding solution involving shape-based retrieval of similar parts.

2 Review of 3D CAD model comparison scenarios

Numerous scenarios can be found that take advantage of comparisons between 3D CAD models, as much in CAD- and PLM-related scientific literature as in commercial documentation. Overall, whether the comparison is done approximately or in detail, it is generally intended to support the work of specialists during a particular engineering process via the assessment of the two modeled 3D shapes' similarity or difference. We classify 3D CAD model comparison scenarios into six *application domains*:

- CAD data translation/remastering,
- Product information reuse,
- Engineering change management,
- CAD modeling management,
- Product rationalization and standardization, and
- CAx model authoring.

We present the first three application domains, as they include the scenarios that are the most frequently referred to in the literature.

2.1 CAD data translation/remastering

A first application domain comprises scenarios involving 3D CAD model comparison as the key for the geometric validation of CAD data translation and CAD data remastering. The purpose of the comparison is to verify the geometric equivalency of two related CAD models; i.e. to ensure that the authoritative 3D data from a source file was adequately and accurately reproduced in a new target file [3,5]. This type of validation is required because of the possible loss or degradation of authority data during the translation (automated) or the remastering (manual) processes. The differences thus located are treated as detrimental and will normally cause the validation to fail.

3D shape comparison methods used for geometric validation are usually metric-based. The compared metrics may be [3,5]:

- global properties, such as the shapes' volume, surface area or centroid;
- entity counts, such as the number of faces, edges or surface types; or
- local measurements, such as the maximum deviation between the models' boundaries (also known as the points cloud or "point-to-part" method).

Metric-based comparison methods provide pass/fail diagnosis on geometric equivalency between heterogeneously formatted models. Some are notably being implemented as "Geometric Validation Properties" (GVP) in application protocols AP203 [6] and AP214 [7] of the ISO STEP standard for product data exchange.

A family of software tools has emerged to address the specific purpose of geometric validation following 3D CAD data translation by means of 3D CAD model comparison. These geometric validation functionalities are generally complementary to 3D CAD data translation engines. They may also be paired with product data quality (PDQ) validation functionalities that check source and target models beforehand for geometric defects that often cause CAD data translation and, thus, geometric validation to fail.

In addition to being capable of reading multiple CAD data formats, geometric validation tools are required to maintain the two compared data sets' integrity prior to their being compared. Any loss or degradation of data that would originate from the validation tool's data processing itself would overthrow the process it is designed to perform. The approaches used to address this issue are either to process the compared data using licensed libraries published by the major CAD systems' editors (e.g. [8,9]), or to operate the originating CAD systems via their API to access and process the compared data (e.g. [10,11]). While the former approach benefits from not requiring costly 3D CAD system installations and licensed seats for the comparison tool to operate, the latter ensures that the CAD data is fully and accurately read by the originating systems, as licensed libraries may be voluntarily left incomplete by issuing parties for competitive motives.

2.2 Product information reuse

As a solution for reducing costs and delays while lowering risks, one aspect of PLM features the retrieval and reuse of parts, products and associated information. 3D CAD model comparison is key to overcoming the challenge as shape can now be perceived as a neutral and effective language to represent and retrieve product data [12]. The problem of retrieving product data based on shape is divided into two steps, each with distinct objectives [13].

The first step is to locate similar parts in the PLM vault, which may contain thousands or hundreds of thousands of parts represented by their 3D CAD models. A model selected as a search key will be compared to other models in order to evaluate their similarity via a given metric which, in turn, will be used to identify and sort a subset of the compared models that can be considered as similar.

The typical shape-based retrieval approach does not involve the comparison of the 3D CAD models themselves. Instead, lightweight shape signatures are being extracted beforehand or “off-line” for each 3D CAD model and stored as meta-data. Large amounts of 3D shapes can therefore be compared quickly to each other and qualitative similarity measures can be computed efficiently, since only the shape signatures are compared.

Many shape signatures, along with extraction and similarity measure algorithms, have been proposed in recent years and duly reviewed [14,15]. Shape signatures are high-level abstractions of 3D shapes and, therefore, possess reduced discrimination capabilities. Unless it is expressly so designed, it is difficult to predict how well a particular shape signature will perform in a given scenario. For instance, machining feature-based shape signatures [16,17] will suit shape-based retrieval tasks better than other shape signatures when the reuse of existing machining processes is the objective.

The second step of product information reuse is to detail the differences between the CAD models considered to be similar as a result of the first step. The previously computed shape signatures, given their reduced discrimination capabilities, are discarded and pair-wise comparisons of each retrieved candidate model with the search key are performed. The goal is to determine if the retrieved pairs of CAD models can rightfully be identified as similar as per the particular reuse objective.

For instance, to determine if a retrieved existing sourced part can appropriately replace another one in a design, sufficient evidence of their interchangeability must be compiled. For that purpose, pair-wise 3D CAD model comparison enables the identification of a common base between two designs, validating that features and/or dimensions, regarded as critical from the viewpoint of the inquiring engineering process, are present in both.

2.3 Engineering change management

Engineering change management represents another domain of PLM that benefits from 3D CAD model comparison. Numerous scenarios requiring a detailed assessment of the modifications applied to a part or a product model can be identified; typical ones include:

- the execution of engineering change orders (ECO) [18,19],
- the impact analysis of a design’s evolution on downstream models [20],
- the automated propagation to downstream models of a change applied to a part’s 3D geometric definition [21], and
- the detection of unauthorized or detrimental modifications applied to 3D CAD or other 3D CAx models [1,10].

Leading 3D CAD systems such as Dassault Systèmes’ SolidWorks® [22] or PTC’s Pro/ENGINEER® [23] offer model comparison functionalities specifically designed to support tasks related to engineering change management. Available feature-based comparison functions enable the location and the evaluation of differences at the parametric level between two CAD models as represented by their respective modeling histories or feature trees. However, the issue of the non-uniqueness of part representations restricts the applicability of such functions to scenarios involving the comparison of related CAD models representing versions of a single part's evolving definition.

3D CAD visualization and collaboration tools also incorporate some model comparison functionalities specifically to support the diffusion of engineering changes throughout an extended organization (e.g. [24,25]). Accordingly, comparison results can only be visualized. Capabilities regarding the characterization of localized differences remain slight because only lightweight or approximated shape models can be compared. As for geometric validation tools, engineering change management scenarios will sometimes be included in their respective sets of possible uses; but, since it is not their primary purpose, their relevance in such scenarios remains limited.

3 Structuring 3D CAD model comparison scenarios

Due to the heterogeneity of scenarios, the selection or the development of an implementation approach for 3D CAD model comparison must be addressed piece-wise. Defining factors such as the purpose, the nature and the composition of the compared data, as well as the inquiring engineering process are key and highly interrelated.

This section presents the three steps of the proposed approach to structuring 3D CAD model comparison scenarios. It also presents the Product-Definition-Model-Formalism for Comparison (PDMF4C) meta-model for representing pre-existing commonality and relationships between compared CAD models.

A high-level UML formalism is used to represent the PDMF4C meta-model. Hence, although set at the conceptual level, the information captured by this meta-model should be rich enough to represent any of the scenarios despite their heterogeneity. It should then provide insight on what should be accomplished next, whether it involves selecting an existing solution (e.g. commercially available tools), or defining the requirements for the development of a new solution approach.

3.1 Identifying the basic function of the comparison

The particular function of a comparison between two models will significantly vary depending on the scenario. It constitutes the first defining factor for any 3D CAD model comparison problems as it enables the following preliminary identification of a *solution domain* and of some basic requirements to assimilate.

Six basic functions for 3D CAD model comparison problems have been identified. As summarized by Table 1, each basic function relates to an elementary question that the process of comparing 3D CAD models is expected to answer. Identifying the basic function also provides insight on how the expected result should be expressed.

The identification of the appropriate basic function can be achieved by characterizing two specific aspects of a 3D CAD model comparison problem:

- *cardinality* – a reference model may either be compared to one single target model (1-to-1, or pair-wise) or to many models (1-to-N) coming from usually large sets; and
- *level of detail* – the amount and the accuracy of information expected from the comparison will vary according to the intended use, ranging from simple "Yes-No" or "Pass-Fail" diagnosis to detailed measures of the located differences.

Table 1 Basic functions of model comparison

	Basic function	Basic question	Expected result
A.	Find duplicate	Which models are equivalent?	Finite sets of objects
B.	Find similar	Which models are similar?	Ordered, scale-based distributions
C.	Detect difference	Are the models different?	Binary (Yes/No, Pass/Fail, etc.)
D.	Estimate difference	How different are the models?	Qualitative, scale-based values
E.	Locate differences	Where are the differences?	Graphical reports describing regions, loci
F.	Measure differences	What are the differences?	Classifications, measures, detailed descriptions

Accordingly, relating both the level of detail and the cardinality allows us to distinguish each of the six basic functions for comparing 3D CAD models, depicted in Fig. 1. Each of these two aspects has an important influence over the problem's solution domain. As it regulates the quantity of comparisons performed in a single occurrence of the scenario, higher cardinalities justify a solution boasting good computational efficiency. On the other hand, high levels of detail understandably command far more methodical difference calculation algorithms and, consequently, more complex difference representation systems.

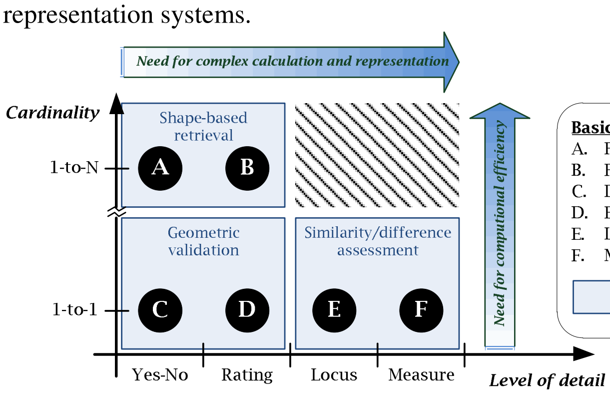

Figure 1 Basic functions and their relation to the required level of detail and cardinality

Three solution domains are identified and related to the six basic functions on Fig. 1. Hence, finding duplicate or similar models within large sets of 3D CAD models relates to shape-based retrieval, the corresponding similarity measures being of qualitative nature, at most. Comparing two models to either check their equivalency according to some given context-specific criteria or to estimate their relative difference with reference to specific characteristics, i.e. to provide a qualitative appraisal of how close or far they are from each other, involves geometric validation. Then, when distinguishing differences between two models, providing their respective locus in relation to the modeled shapes and, furthermore, when categorizing them or measuring their geometric magnitude, we refer to the detailed assessment of the models' similarities or differences.

3.2 Developing the reference/target relationship

Fundamentally, a relationship must already exist or must be defined between two CAD models for them to become the subjects of a comparison. Informally, such a relationship is established when one of the models is identified as the reference model; for instance, the query shape in shape-based retrieval or the source file in the geometric validation of a CAD data translation task.

Conceptually, we introduce a representation of this relationship within the PDMF4C meta-model through the definition of the **Comparison** association that relates two **Model** instances. As represented in Fig. 2, the attributes of the **Comparison** association are defined in order to allow the capture of the comparison scenario's first defining elements, i.e. the basic function of the comparison and the related aspects of level of detail and cardinality.

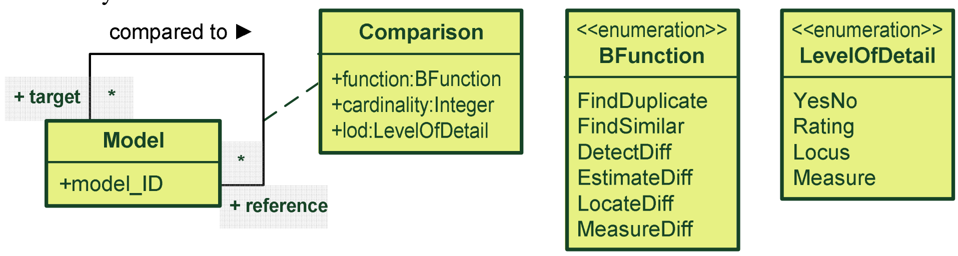

Figure 2 Representation of the comparison association

The reference/target relationship between the compared models is obviously central to the comparison problem. Still, it is assumed that a more elaborate representation of a 3D CAD model comparison scenario via the PDMF4C will add to the input and significance of such a relationship in the development of an implementation approach. Besides providing directionality to the comparison, this meta-model may also reveal preexisting elements of commonality between the models – for example, in how they are represented, what information they convey and to what intent.

3.2.1 The four core concepts of modeling

To organize this facet of the 3D CAD model comparison problem, we were inspired by Caplat's theory on meta-modeling [4]. In Caplat's theory, four core concepts involved in fundamental modeling are identified and related, as depicted in Fig. 3: the *subject*, the *language*, the *point of view* and the *model* itself.

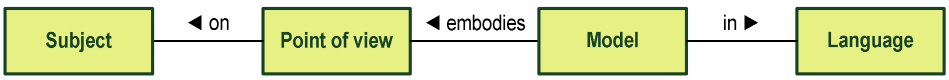

Figure 3 The four core concepts involved in modeling according to Caplat [4]

The *subject* represents objects, individuals or situations that form a set because they relate through recognizable common traits as per the *point of view*. The *model*, itself a constructed object, embodies a *point of view* in accordance with the rules imposed by the *language* it is expressed in – rules which are a priori independent of the *subject*.

Basically, every model is a form representing content – a concrete and analyzable representation conveying a meaning, a means of sharing knowledge.

In the specific context of CAD and, correspondingly, of the proposed PDMF4C meta-model, the **Product** constitutes the modeling subject. Accordingly, the CAD **Model** embodies a temporarily and contextually set **Definition**, a particular point of view on the expected features and functions of the **Product** and **Product_Instances** projected to be manufactured, by detailing a finite set of **Specification** instances. It is expressed in a given and sometimes tool-specific CAD **Formalism**. From the perspectives of engineering and product development, the CAD model is a communication tool for the different actors in the design, manufacturing and other processes of the product throughout its lifecycle.

The four CAD-specific core concepts of **Product**, **Definition**, **Model** and **Formalism**, represented in Fig. 4, constitute the core elements of the PDMF4C meta-model for representing pre-existing commonality and relationships between compared CAD models. Accordingly, the development and refinement of the informal reference/target relationship is to be approached from two perspectives: via the models' respective product definitions that they embody or via the formalisms they are respectively expressed in.

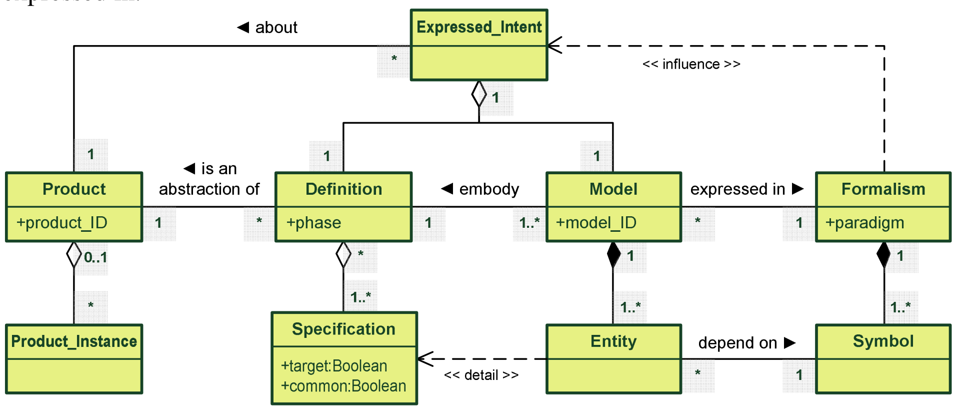

Figure 4 Representation of the PDMF4C meta-model core concepts

3.2.2 *Relating the compared model's definitions*

Developed from a finite set of **Specification** instances, a **Definition** is regarded as the subjective and flexible element of product modeling. For instance, at the beginning of the conceptual design phase, the definition may only include initial requirements about the product, which implies a high level of abstraction. It must, however, evolve considerably to reach the status of detailed and released design, which implies a much lower level of abstraction. Even though they are abstractions of the same product, a product's conceptual and detailed definitions will be represented as distinct **Definition** instances in the meta-model. They represent distinct sets of specifications, even if the latter encompasses the former.

As an outcome of a 3D CAD model comparison scenario, common subsets of specifications, from the single instance to an entire product definition, will normally be either validated or identified. For instance, in the geometric validation of translated 3D CAD data, comparison of the source and target models is normally required to validate that both models systematically embody the same geometric definition of a product – a typical subset of specifications embodied by 3D CAD models.

Clearly identifying target specifications through an appropriate level of aggregation is advisable. In the PDMF4C meta-model represented in Fig. 4, **Specification** instances are characterized by two attributes: the 'target' attribute aims at identifying **Specification** instances that represent the objects of the comparison, while the 'common' attribute aims at identifying the specifications that are expected to be common between the two models.

3.2.3 Relating the compared model's formalisms

To embody a **Definition**, a **Model** instance must be expressed in a particular **Formalism**, which stands for the core modeling concept of *language*. In the PDMF4C meta-model, an element of a model is called an **Entity**. It is based on a particular **Symbol** from the **Formalism** the **Model** is expressed in, and it is structured according to a defined grammar. Formalisms have a determining influence on the capability to express intent (**Expressed_Intent**) about a product. That is, symbols available to express a product's definition and its specifications via the CAD model are fixed at the moment a formalism is used, both in their form and in their semantic use.

3D CAD file formats constitute examples of distinct formalisms. Modeling paradigms, represented here by the 'paradigm' attribute of the **Formalism** concept, define the foundations – a coherent set of modeling object classes, their respective features, their relationships, the rules of use, the constraints, etc. – on which one or many formalisms and one or many methodological approaches to modeling rely. In 3D CAD, boundary representation (B-Rep), constructive solid geometry (CSG) and tessellation represent examples of modeling paradigms. Accordingly, the STEP AP203 formalism [6] is based on the B-Rep paradigm, as is the Parasolid® formalism. Graphical representations of 3D CAD models must be considered as related, yet distinct models, since they are expressed in formalisms based on a different paradigm (tessellation).

Fig. 5 details how 3D CAD formalisms may relate via the representation of a third section of the PDMF4C meta-model. 3D CAD formalisms are implemented or processed by **Software_Tool** instances. Depending on the function they implement, they can be classified into two subtypes of tools relevant to 3D CAD model comparison scenarios: **Translator** instances or **Editor** instances,. **Software_Tool** instances are usually integrated into **System** instances such as 3D CAD systems.

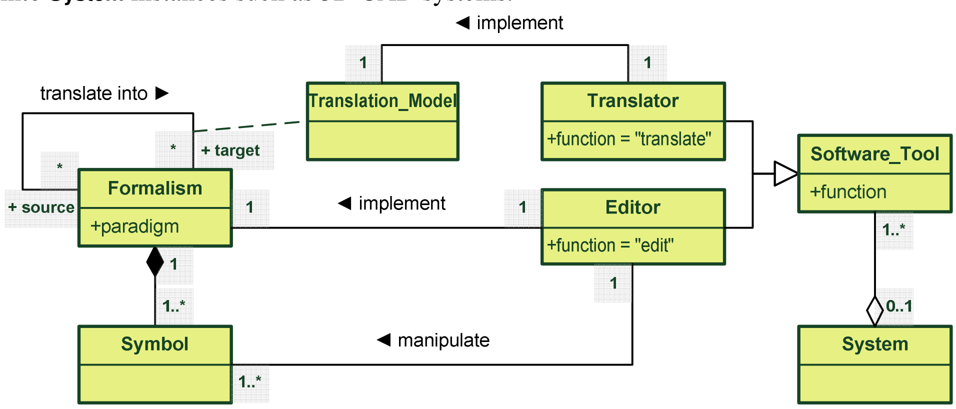

Figure 5 Representation of the **Formalism** and **Software_Tool** concepts

The function of a software tool classified as an **Editor** is to enable the creation and modification of a model by instantiation and manipulation of a particular formalism; consequently, it manipulates the symbols belonging to the formalism it implements in accordance with its rules and grammar. Likewise, as depicted in Fig. 5, a **Translator** translates 3D CAD models by implementing a **Translation_Model** that associates elements of a source formalism (symbols, rules, grammars) to a target formalism.

Translation models are not unique. Many translators may be available to perform, with divergent results, a single CAD data translation task. It is also acknowledged that these models may not be optimal, either. Symbols may be abstracted or left unprocessed due to the source and target formalisms' different abilities for expressing specifications. However, it is important to distinguish the scenarios where the absence of a bijective translation model is considered to be detrimental – e.g. the well-known issue of loss or degradation of data as a result of its translation [3] – from those where it is intended – e.g. the extraction of shape signatures in shape-based retrieval scenarios, as further detailed in the example of Section 4.

3.3 Identifying the inquiring and inquired processes

Even though it represents a single concept, the identification of the processes in the PDMF4C meta-model is important and necessary. **Process** instances embody branches of knowledge with their own distinct reasoning approach and interpretation rules regarding the product in development. As represented in Fig. 6, they relate to the definition of a 3D CAD model comparison scenario via three already-defined concepts: the **Expressed_Intent**, the **Software_Tool** and the **Comparison**.

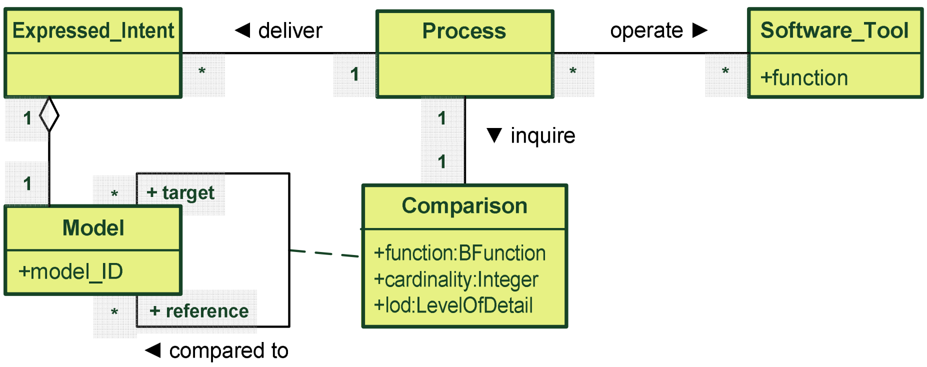

Figure 6 Representation of the **Process** concept

When engaged in product development, a process delivers one or many expressed intents about the product. It owns the particular point of view on the product's expected features and functions which develop into a definition and are materialized by a model. Hence, identifying the process that delivered a model subject to a comparison amounts to identifying one of the comparison's *inquired* processes. As two 3D CAD models are compared, the inquired process or processes' interpretations of the product need to be considered and, thus, weigh in on the calculation and the representation of the differences.

Also, processes within an organization exploit or contribute to the 3D CAD models of new or existing products through the realization of specific tasks by means of software tools. These tools implement or process specific formalisms which have a real influence on the initial expression of intents about the product. Thus, the association of processes and specific formalisms via the software tools supports the recognition of distinct semantic domains.

Finally, identifying the comparison's *inquiring* process amounts to specifying the initial requirements on how the located similarities and/or differences need to be represented. Proper difference representation is central to the 3D CAD model comparison problem as it directs the interpretation of the calculated results by the inquiring process and provides efficiently for further manipulations.

4 Structuring a typical design reuse scenario

This section presents an example of a 3D CAD model comparison scenario structured and represented by means of the proposed PDMF4C meta-model. To better demonstrate the meta-model's representational ability, the scenario of design reuse via shape-based retrieval has been chosen for its reliability, having already been explored in prior works [14,15]. Design reuse is a specific scenario from the product information reuse application domain.

The shape-based retrieval approach illustrated here has been implemented by Siemens PLM's Geolus Search® engine [26]. One of the most important applications of Geolus Search® has been in purchasing, with buyers evaluating the prices for new parts by comparing them with the costs of similarly shaped existing parts [27]. This example shows the pertinence of the PDMF4C meta-model in the conceptual representation of 3D CAD model comparison scenarios.

4.1 Design reuse via the shape-based retrieval of 3D CAD models

As described in Section 2.2, the generic product information reuse scenario incorporates two distinct 3D CAD model comparison problems and, thus, two distinct functions: (1) to find candidate models similar to the query model and (2) to locate the similarities and/or differences between the query model and a reduced number of candidate models.

This example focuses specifically on the first problem specifically applied to design reuse. Accordingly, shape-based retrieval constitutes the solution domain, as the problem is characterized by a 1-to-N cardinality and requires a low level of detail. The need for computational efficiency is significant, whereas the requirements regarding difference calculation and representation remain minor.

This scenario is represented via the PDMF4C meta-model in Fig. 7. A candidate 3D CAD model (target, left) and a query 3D CAD model (reference, right) are each represented as initially unrelated **Model** instances embodying the design **Definition** instances of distinct **Product** instances. A **Comparison** association instance clearly identifies the comparison's basic function and characterizing aspects, as well as the reference and target **Model** instances.

In this design reuse scenario, the design process is the only one involved; therefore, the single Design:**Process** instance is associated with each of the **Expressed_Intent**, **Software_Tool** and **Comparison** instances. Shape is also identified as the feature on which the similarity of the modeled parts will be based; two **Specification** instances identifying the parts' specified shapes as the objects of the comparison are represented and associated as subsets of the **Definition** instances.

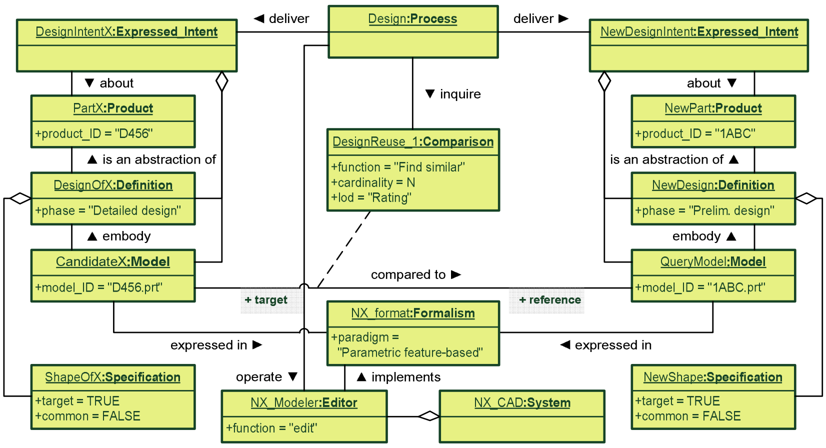

Figure 7 Representation of a typical shape-based retrieval scenario

4.2 Geolus Search® shape-based retrieval solution

Shape-based retrieval methods resort to shape signatures to represent a models' content and thus accelerate the highly recurrent comparison process. As illustrated in Fig. 8, indexing of candidate 3D CAD models is performed by a shape signature extractor implementing a shape signature algorithm.

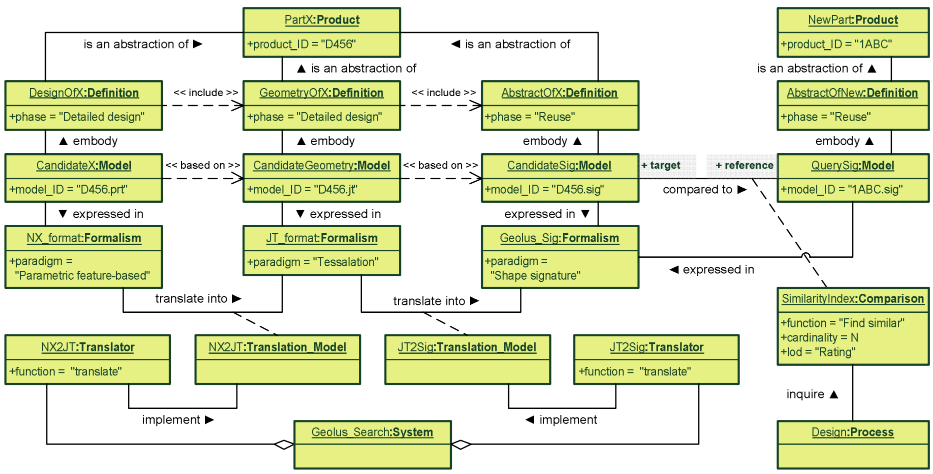

Figure 8 Representation of the shape-based retrieval approach of Geolus Search®

The query model's shape signature must also be extracted in order to be compared to those of the candidate models (excluded from Fig. 8 due to space constraints). The resulting shape signatures are regarded as new **Model** instances that now embody specific yet very limited subsets of specifications from the initial design definitions embodied by the original 3D CAD models. Once abstracted, the contents of all 3D CAD models can be compared to evaluate and rank their similarity.

One particularity of the Geolus Search® solution to shape-based retrieval of 3D CAD models resides in the need for a translation of the original 3D CAD models to a tessellation-based format before the extraction of their respective shape signatures, such as Siemens PLM's proprietary JT format [27]. Such pre-processing aims at ensuring the 3D CAD interoperability of the 3D CAD repository. Since a tessellation-based formalism has a limited capability to express design intent, shape signatures are only extracted from approximated models embodying reduced geometric definitions. In the current scenario where shape specifications were identified as the objects of the comparison, such particularity will conform to the initial problem representation.

However, if it had been otherwise – e.g. if specifications regarding form features were the objects of the comparison – the described solution would have been unsuitable for this design reuse scenario. Accordingly, it shows how important it is to identify and structure the defining factors of each 3D CAD model comparison scenario in order to efficiently identify the right comparison solution.

5 Conclusion

As described in this paper, 3D CAD model comparison contributes positively to PLM, as it promotes the resourceful use and reuse of product data at various stages of a product's lifecycle. 3D CAD models are a means for sharing knowledge for use by the different actors from the product lifecycle; thus, the tools made available to extract and process that knowledge need to assimilate specific settings and objectives. The proposed three-step approach and related PDMF4C meta-model are designed to structure and elaborate 3D CAD model comparison scenarios, providing better representation of the problem to be addressed from a case-based perspective.

The function of 3D CAD model comparison, the compared models' initial compositions and shared relationships, as well as the inquired and inquiring processes, constitute defining factors for comparison scenarios. Depending on the basic function, the results expected from a 3D CAD model comparison will range, in terms of representation, from simple pass/fail diagnoses to complex data structures. Preliminary elements of commonality between the compared models on aspects such as their respective formalisms, embodied product definitions or overall expressed intent are sure to exist and need to be formally identified.

Our current work on 3D CAD model comparison addresses the issue of difference representation as it effects the transposition of engineering change between 3D CAD models. The objective is better interpretation and manipulation by the inquiring process of the differences calculated between two 3D CAD models. Working with the PDMF4C framework has allowed us to thoroughly represent the scenario of engineering change transposition, which incorporates 3D CAD format heterogeneity. From a large-scale perspective, the proposed approach will benefit numerous actors looking to efficiently exploit 3D CAD model comparison in order to reduce product development costs and delays. A manufacturing process planner searching for similar existing parts to reuse manufacturing processes for new parts, or an engineering change committee assessing the overall impact of design changes applied to revised parts, would be just two obvious examples.

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Constraint propagation on PLM Databases: Application to the design of automated production system

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Abstract: In this paper we present a generic mechanism of interaction with databases (PLM) based on constraint propagation. Then we illustrate it on the case of designing of automated production system (APS) element, i.e. we use this mechanism in order to achieve effective filtering of prefabricated components instantiated on catalog to the satisfaction of a specification. Finally, our approach is illustrated on the choice of prefabricated components for the realization of a positioning system.

Keywords: CSP, interval computation, PLM, design, automated production systems.

1 Introduction

On the one hand product lifecycle management (PLM) is defined as a concept for the integrated management of product related information through the entire product lifecycle [1]. On the other hand, according to [2], PLM provides a platform of management powerful information, able to support the complex relationships that exist within computer models, test data and simulation, different versions of projects, management of nomenclature, information tools of production, content management, product support, and all other activities related to the product.

So currently, information system is the main function of the PLM system; however, the current PLM implementation stage at most organizations still does not apply the lifecycle management concepts thoroughly [3].

Many surveys focus on product models based on the constraints, like [4, 5, 6, 7, 8]. Their objective is to find a solution or a set of solutions that satisfies all the system constraints. However, further to the information lack, none of these research works uses the PLM system to find an optimized solution.

So it will be interesting to search new effective mechanisms to interact between the product models based on constraints and the PLM's databases.

In the present work, two mechanisms are proposed. These mechanisms are developed with the C++ and SQL languages. Finally, a case study is proposed, it is the case of sizing an automated production system (APS) element which is based on components CAD files stored in a PDM system.

2 Constraint propagation on finite domains and intervals

From the moment the customer's requirements can be translated as equations, inequalities, variables or compatibility relationship between components, it is possible to integrate them as constraints in our system. So we use Constraint Satisfaction Problem (CSP) to model the customer's requirements as constraints.

2.1 Constraint Satisfaction Problem

A CSP [9, 11] is defined by 3-tuple (X, D, C) such that:

- $X = \{x_1, x_2, x_3 \dots , x_n\}$ is a set finite of variables which we call constraint variables with n being the integer number of variables in the problem to be solved.
- $D = \{d_1, d_2, d_3 \dots , d_n\}$ is a finite set of variable value domains of X such that:

$$\forall\, i \in \{1, \dots , n\}, x_i \in d_i \qquad (1)$$

- $C = \{c_1, c_2, c_3, \dots , c_p\}$ is a finite set of constraints, p being any integer number representing the number of constraints of the problem.

$$\forall\, i \in \{1, \dots , p\}, \exists\, X_i \subseteq X \,/\, c_i\,(X_i) \qquad (2)$$

Solving a CSP boils down to instantiating each of the variables of X while the set of problem constraint C, and at the same time satisfying the set of problem constraints C.

Here, a constraint is any type of mathematical relation (linear, quadratic, non-linear and Boolean …) covering the values of a set of variables [9].

2.2 Computing by intervals to resolve numerical and discrete CSPs

To solve a CSP, we should take into account the type of the constraint variables. Therefore a discrete CSP (which is on integer variables) is different from a continuous CSP (which is on real variables).

- The discrete CSPs: are based on enumeration and filtering. This filtering, also called constraint propagation, enables the definition domains of variables to be reduced as the resolution process evolves. To solve discrete CSP, the methods are ones arising from operational research and artificial intelligence. The first work dates back over thirty nine years [10, 11, 12, 13].
- The continuous CSPs: To exceed the limitation of these CSP at discrete variables we developed CSPs with domains at continuous variables at value in real intervals. This solving technique by intervals is the synthesis between the interval analysis of [14] and the CSPs [15]. Many techniques are developed; we find an example in [16]. In the following, we are interested by these CSPs.

2.3 Using Table Constraint

We propose to use the constraint propagation on the intervals to filter in a components database the necessary instances to realize an ASP element in order to satisfy a specification. This specification contains a set of constraints which should be satisfied.

So we use the Table Constraint, with which we can introduce the different constraint of the system that we design. A table constraint is a global constraint posted on a table. Each row of a table constraint is considered as n-tuplet of consistencies' values. For example (see Table 1) if the value x_1 must be greater than 13 and x_3 must be different to 7. So the rows 1, 2, 3 and 5 are automatically removed from the table by constraint propagation. Only lines number 4 and 6 remain in the table constraint.

Table 1 Example of Table Constraint

	x_1	x_2	x_3	x_4
1	3	3.5	10	0.6
2	7	9.7	6	0.1
3	12	8.8	4	0.4
4	19	5.1	1	0.3
5	24	6.3	7	0.7
6	29	7.2	11	0.5

Consider the following specifications:

$$x_1 \in [6, 23] \tag{3}$$

$$x_2 \in [2.1, 8.9] \tag{4}$$

$$x_3 \in [1, 11] \tag{5}$$

$$x_4 \in [0.2, 0.6] \tag{6}$$

$$x_1 + x_2 > 12.1 \tag{7}$$

$$x_3 \neq 6 \tag{8}$$

To satisfy the specifications we resolve a numeric CSP whose the quadruplets (x_1, x_2, x_3, x_4) are: (12, 8.8, 4, 0.4) and (19, 5.1, 1, 0.3).

This principle, illustrated here on a single table constraint, may be generalized to any number of tables. So it's possible to express the relationships to satisfy between attributes of different tables (i.e. in the case of the ASP design between many prefabricated components). Then the system will return the combinations of components instantiated, solutions in finite number.

3 Mechanisms to interact with database management system

In this paper we use two mechanisms to interact with the PLM systems. So we will consider a relational database which is searchable through SQL language (see Figure 1). The purpose of these mechanisms is to provide the best solution according to catalogs of different components required by the customer, in order to design a system.

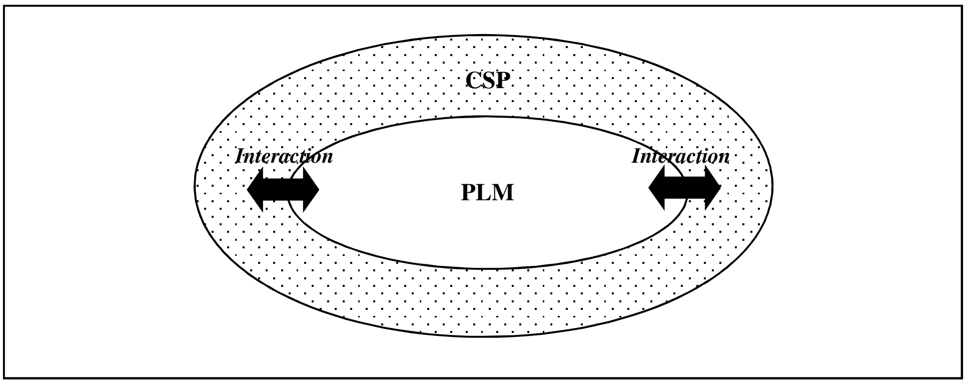

Figure 1 Interaction principle between PLM and CSP

3.1 Using all the data of the base

This first mechanism consists to extract all the data from PLM system and insert it in the product model. We present the mechanism principle in the figure 2.

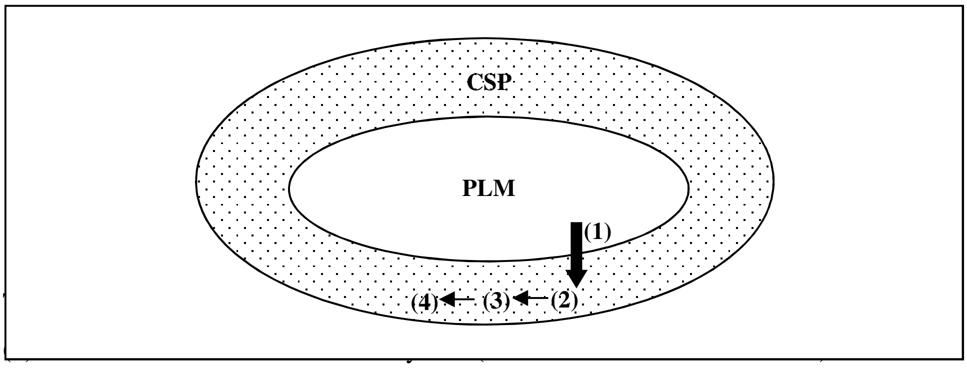

Figure 2 Interaction principle of the first mechanism

The mechanism steps are the following:

(1) Select all the data from the PLM system (SELECT FROM * CATALOG).

(2) Insert the data in a constraint table in the CSP system.

(3) Constraint propagation.

(4) Solve the problem.

3.2 Sorting the data which satisfy the constraints

The second mechanism consists on sorting the PLM's database and taking only the admissible solutions which satisfy the system constraints. The following figure presents the mechanism principle.

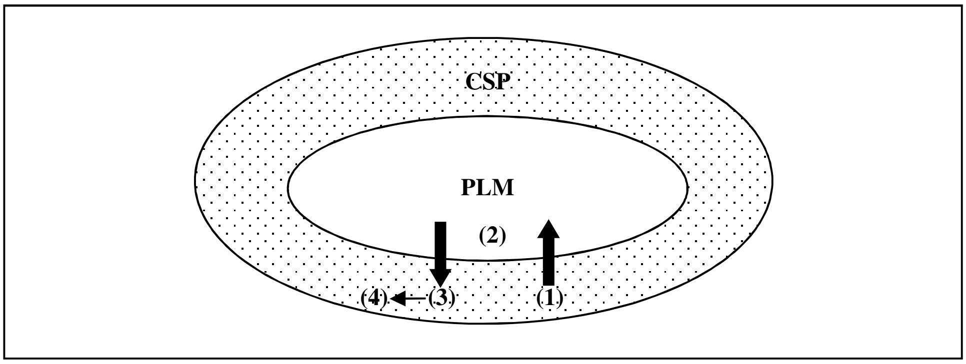

Figure 3 Interaction principle of the second mechanism

The mechanism steps are the following:

(1) Constraint propagation.

(2) Select the admissible solutions from the PLM system (SELECT FROM CATALOG WHERE "the constraints are satisfied").

(3) Insert the data in a table constraint.

(4) Solve the problem. This second approach is more efficient in term of resolution efficiency than the first, because we have fewer registrations to recover. So we recover only the necessary records for the resolution. Therefore the table constraint is smaller and the filtering during the resolution is more efficient.

4 Applicative case

4.1 Presentation of the motorized rail

The motorized rail systems [17] allow the control of moving parts of automated machines. We see in the Figures 4 and 5 that we should make a movable plate mounted on pebbles rectilinear movement along a rail mounted on a machine frame. This movement is driven by a three phase motor linear (Figure 6). The components that we use to design the ASP element are fabricated by ETEL company. These various components are available on catalog but also with specific measures.

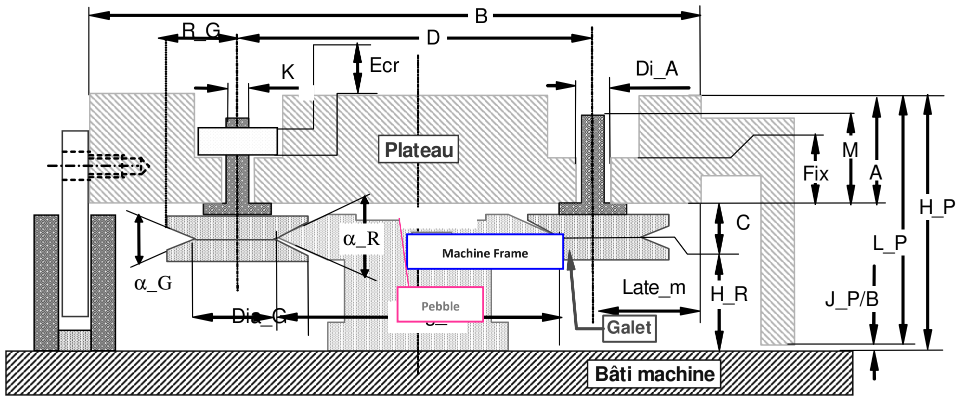

Figure 4 Parameterization of a positioning system by motorized rail - Transverse view

We propose to implement a linear motor whose moving part is secured to the plate (left side of Figure 1) and the fixed part with permanent magnet is attached to the machine frame.

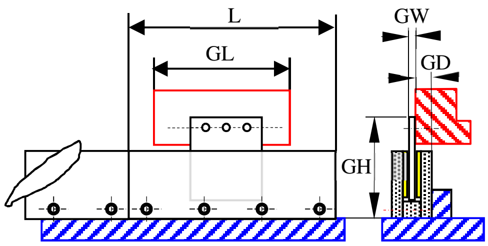

Figure 5 Motor implantation - Longitudinal view

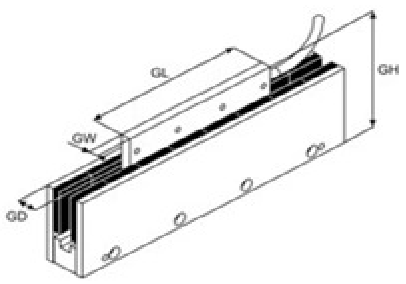

Figure 6 ETEL three phase motor linear

4.2 Modeling the system

We see that the motorized rail can be represented by three essential parts: The moving part, the rail and the motor.

The moving part contains the plate and the pebbles. And the motor have fixed part and moving part.

The global parameters considered in this system are: J_{BP}, H_P. And the remaining parameters are:

- Rail parameters: $Larg_R$, α_R , H_R.
- Pebble parameters: Dia_G , α_G , R_G , K , Ecr.
- Plate parameters: D , C , A , M , Fix , e_m , Di_A , L_p , B.
- Motor parameters: GD , GW , GL , GH , L.

All these parameters present the product model of the motorized rail system. The figure 7 indicates the interaction principle between the PLM and CSP to resolve the current problem.

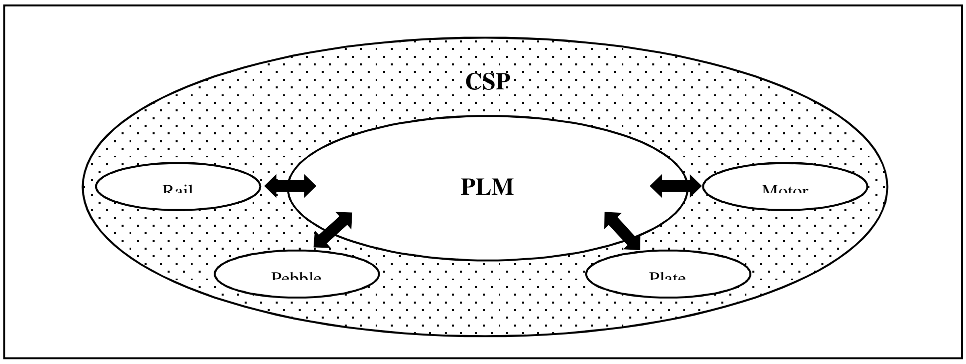

Figure 7 Interaction principle of the first mechanism

In order to illustrate the principle of our proposal, we voluntarily limit in that section to the expression of different geometric constraints to be met to qualify for assembly. The full study should of course take into account the constraints of fixing the engine on the frame and the plate and the energy constraints of the specification (target speed, effort to convey ...).

The customer's requirements of the motorized rail are represented by the following equations:

$$D = Larg_R + Dia_G \tag{9}$$

$$H_p = H_R + C + A \tag{10}$$

$$B = Larg_R + Dia_G + 2*Lat\ e_m \tag{11}$$

$$Fix + Ecr \leq M \tag{12}$$

$$\alpha_G = \alpha_R \tag{13}$$

$$K = Di_A \tag{14}$$

$$A - Fix \geq Ecr \tag{15}$$

$$J_{BP} = H_p - L_p \tag{16}$$

$$GH > H_p - A \tag{17}$$

$$GH < H_p \tag{18}$$

$$B - GD > Lat\ e_m - R_G \tag{19}$$

$$GL \leq L \tag{20}$$

$$GW \leq 2*GD \tag{21}$$

This set of relationship defines a CSP to resolve with the various constraint tables of mounting parameters (plates table, pebbles, rails, linear motors available on catalogs.

4.3 Solving the problem and results

A software prototype has been realized with the C++ language using the IlogCP [18] library of constraint propagation. This prototype interacts with the database of the components parameters into using one of the two mechanisms mentioned above. By cons, we have introduced in the database only the linear motors catalogs. The figure 8 illustrates an example of a linear motor extracted for the catalog.

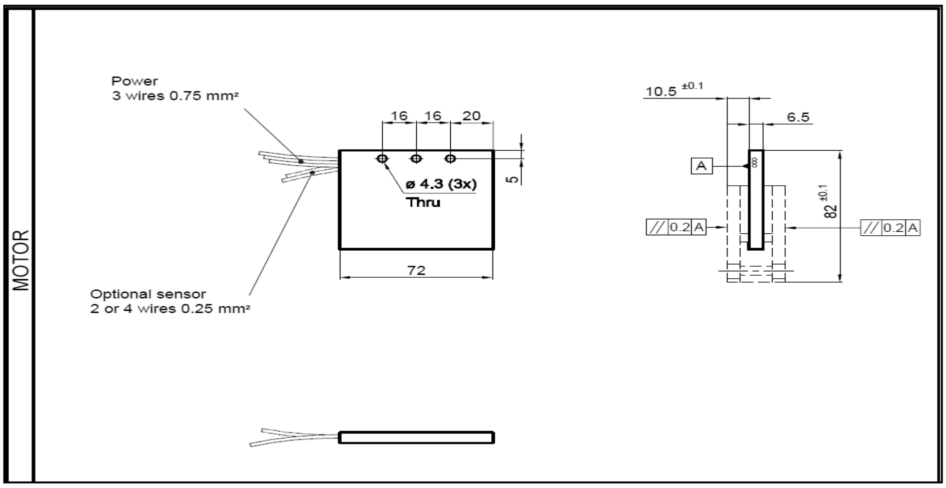

Figure 8 Example of linear motor extracted for catalog

From the catalogs of linear motors, we were able to extract the lower and the upper bounds of each parameter:

- $GD = [10.5, 14.8]$
- $GW = [6.5, 8.4]$
- $GL = [72, 520]$
- $GH = [82, 124]$
- $L = [64, 512]$

The other parameters remained undefined. The figure 9 represents the case of our study.

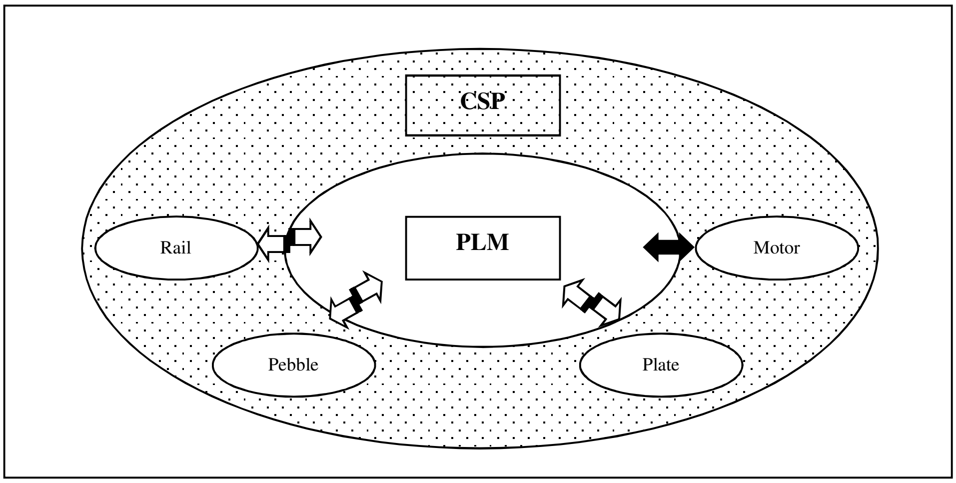

Figure 9 case of the study.

We chose the second mechanism to solve the problem, and we obtained the following results as presented in table 2.

We see that the motor parameters values are well defined, by cons, the other parameters are arbitrary. To find suitable solutions we need to introduce the catalogs of the rail, the pebble and plate in the PLM system to interact with the CSP part.

5 Conclusion

We proposed in this paper a generic prototype software which is based on the techniques of interval computation and constraint propagation. Our approach allows the interaction between the CSP system and the PLM system. According to a specification that contains the system constraints and a database of components catalogs, all the combinations of eligible components will be generated. Finally, we illustrate our ideas on a case of motorized rail design. By cons, the study case was limited only to determine the motor parameters. We can apply our approach to determine all other parameters by integrating catalog data in the PLM system.

In fact, our approach deserves to be evaluated on the databases of larger components associated with various specifications of systems.

Table 2 Application results

Variable	Value (mm)	
$Larg_R$	10000	
α_R	360	
H_R	82	
Dia_G	9,312	
α_G	360	
R_G	1000	
K	1000	
Ecr	4,35	
D	10000	
C	1,065	
A	1000	
M	1000	
Fix	1000	
e_m	0,29	
Di_A	1000	
L_p	82	
B	10000	
GD	10,5	Motor parameters
GW	6,5	
GL	72	
GH	82	
L	64	
J_{BP}	1000	
H_P	1082	

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Product Lifecycle Simulation Applying Semantic Data Management

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Abstract: Product lifecycle simulation (PLCS) has been given ever more attention as the manufacturers are competing with the quality and lifecycle costs of their products. Especially, the need of companies to try to get a strong position in providing services for their products and thus to make themselves less vulnerable to changes in the market has led to high interest in PLCS. A short summary of current status of PLCS is presented especially related to the poor integration of data in product lifecycle management systems and in PLCS. The potential of applying semantic data management to solve these problems is thoroughly discussed in the light of recent development. A basic roadmap how the above-described problems could be tackled with open software solutions is presented. Finally, this paper reviews the emergent Web technologies such as the Semantic Web framework and the Web services.

Keyword: Product lifecycle, Simulation, Semantic, Data management, Semantic Web, Web services

1 Introduction

The challenge in manufacturing and service-based business can be compressed into the following: to optimise the set of maximum quality (for the purpose) with minimum resources fast into the market. This multi-objective optimisation task has three complex sub-objectives that are usually conflicting in business. Increasing quality usually increases costs and may also require more time to get the product to the market. Simulation-based product development methods provide ease for this by providing ability for concurrent design of different subsystems of the product and enabling the coupling of the different design areas early in the development process. The trend of increasingly use simulation in the early phases of the product lifecycle can be seen e.g. in vehicle and aeroplane industry, where the current short length of the design cycle is mostly achieved by using computational methods. The application of simulation in product process has been seen as one of the key factors for success of industry [1, 2, 3].

As the application of computational methods spreads more widely into the manufacturing industry, the companies are forced to look for new areas for their business to increase the stability of the business. Especially in heavy machine industry, the service business has become the second and equally important supporting pillar for the business. This, on the other hand, sets more demands on the application of simulation in the product process. While the service business has increased its importance for the overall business, the effect of the product design has to be taken into account for the whole product lifecycle and the service business. For a product of 25 years expected lifecycle, design decisions that hinder the service business for the whole product lifecycle have high importance. This means, to optimise the whole business and product lifecycle, all the aspects of the product lifecycle need to be taken into account in the product development phase. On the other hand, the simulation models provide useful platform for product use phase optimisation, especially for large and complex products.

The basic purpose of information and communications technologies (ICT), such as information systems, decision support systems, and simulation, is to acquire and represent information and knowledge [4, 5, 6]. It is believed that the more complete data, information, and knowledge a company has in different circumstances, the more accurate decisions are made [7]. Turban et al. [7] also state that in such a situation the decision maker can be viewed as a perfect predictor of the future.

Several approaches have been followed by companies for the reasons of high competition and product lifecycle management (PLM) is one of these. The historical development of PLM, i.e. its evolution has originated from two directions [8]. The first one starts from enterprise management and continues with the material resource planning (MRP), enterprise resource planning (ERP), customer relationship management (CRM), and ends in the supply chain management (SCM) before it evolves into one of the parts of the PLM. The other part has its background in the management of product information, i.e. computer-aided design and manufacturing (CAD/CAM) and product data management (PDM) systems. Those early systems were limited to engineering information, which required engineering skill and knowledge. The PLM emerged during the late 90's and its main objective is to manage all the information that passes through all the phases of the product lifecycle such as design, manufacturing, sales and after sales. Historically the ICT's used for the reasons of PLM have been software's such as ERP, CRM, PDM, SCM, and demand chain management (DCM) etc.

However, the software simulation of the product lifecycle has become important as well since it provides solution for the complexity of decision making, while taking into consideration the interest of the whole enterprise. The complexity derives from the situation of dealing with various layers of decision making within a system [9]. Its advantages are becoming clearer as its impact as well because of the new ICT's such as Semantic Web, Web services, and ontologies. This has been shown in this work by the OpenModelica open modelling software together with semantic data definition based on the use of the Simantics platform.

While the application of the modelling and simulation in product process is becoming more common and widely used, the challenge of organising and managing the data related to it is becoming more critical. This is due to the scattering of the data into many information systems, because of the variety of the form of the data, and due to the requirement of easy accessibility of the data. PDM and PLM systems are attempting to answer to the request for centralised information systems for data management, but they are still lacking many important features, such as flexible business and organisational simulation capabilities.

In this article, the challenges and requirements for PLCS are discussed. In addition, the recent improvements in data management and application of semantic data model are discussed. Moreover, are the World Wide Web Consortium (W3C) reviewed based on the latest results on Web technologies such as the Web technologies for data management and Web services. This is concretised with an example of applying system dynamics simulation. The system dynamics modelling and simulation are done on a simulation platform utilising semantic data management for modelling data.

2 Requirements for product lifecycle simulation

The interest towards PLCS has increased remarkably when manufacturers have got interested in providing services for their products in order to make themselves less vulnerable to competition and variation in sales. Another factor that has raised the interest in PLCS is the possibility of comparing varying design choices in order to make the product technically superior, environmental friendly, and optimal design when the complete lifecycle is considered. Today many companies use PLM programs in order to handle the design process of their product. Naturally it could be assumed that this kind of system should provide a good basis for PLCS. Unfortunately the current level of PLM systems is far from optimal [10]. In their paper [10] they discuss the features of the most widely used PLM systems and show that there are quite remarkable gaps in these systems when their capability of covering the complete lifecycle of products is considered. Another important issue is that the capability of existing PLM systems to pass information between various design and manufacturing programs is very limited. The reason for this is that typically a great number of programs are used to cover the different aspects of a product's lifecycle. As these programs are separate they do not easily pass data between each other. In fact, in some cases the only way of passing information between programs is to do that manually. Clearly from this follows the most important aspect that needs to be solved when PLCS systems are built: There has to be a working solution for passing data between separate programs and systems. Also the level of detail must increase as the product goes through different phases in its lifecycle.

When defining an ideal PLCS system, after the data issue has been solved comes the priority list of what kind of simulations should be available at different stages of product's lifecycle, i.e. the same studies should be possible to make either based on more limited data in the early stages and with more and more reliable data at later stages: Principal design choices, i.e. does it run on skis or wheels? What are the loads and stresses of the product for required performance? What are the cost impacts of the selected structures and components on the product lifecycle? What kind of maintenance policy is optimal? Lifecycle cost (LCC) and lifecycle assessment (LCA) analysis.

3 Semantic data model for simulation data management

The concept of using simulation for predicting the influences of design phase decisions to the whole product lifecycle, including the product's functional features and also the economic, environmental, and business impact, sets high demands on information technology (IT) systems and their users. Depending on the objective, application of modelling and simulation to a single complex physical phenomenon can itself become challenging. Combining many engineering domains together with organisational, business, environmental, and other possible domains, modelling these systems, and successfully simulating the overall system can also become a difficult task. This is due to increase in complexity of the numerical computation and the amount of data involved in the process.

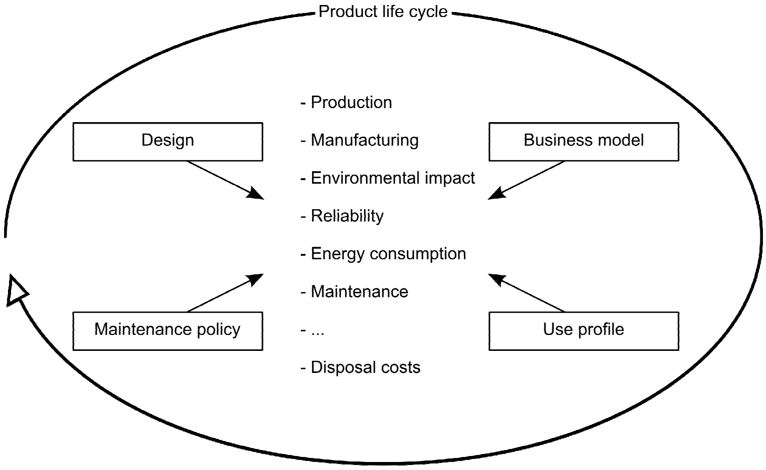

Figure 1. Interconnections of selections and policies on impact topics during product lifecycle.

The typical evolution of the application of computational methods in product process is illustrated in Figure 1. In the figure, the first stage of applying computational methods in product process is to use simulation for some local design detail, such as analysis of component dynamics. In this stage, simulation is used as a tool for a specific problem but it does not affect remarkably the overall design or product process. In the second stage, simulation is used for creating virtual prototypes of the product or its major subsystems. With a virtual prototype, the overall function and properties of the product or its major subsystems can be defined with minimal number of physical testing. In this stage, simulation has some effect on the development or product process, but it does not run it. In the third stage, simulation is consistently applied before detail design and it is driving the design process. The major difference of this stage compared to the application of virtual prototyping is not in the quality of the simulation tools or in the size or complexity of the simulation models but in the design process itself. Because the simulation is the driver of the design process, the design data, including modelling data, simulation results data, and auxiliary data for the process, has to be integrated into the process seamlessly. The fourth stage extends the application of simulation from design scope to the overall product lifecycle scope, including the effects of design decisions to business and environment. While applying simulation more extensively in the product process, the requirements of data management become more crucial. Integration of different computational tools in product development may be cumbersome. As an example, the exchange of data between different CAD systems has been a challenge for as long as these tools have been in use in industry. One of the most important reasons for this is the complexity in software application internal data models. The other important reason is the closed nature of commercial tools. Supporting the data models of other software applications, even inside the same computational domain, is difficult. Extending the communication and data integration of software applications to different engineering disciplines and even further to include software applications focusing on business, environment, and organisational process management, makes the challenge even more difficult.

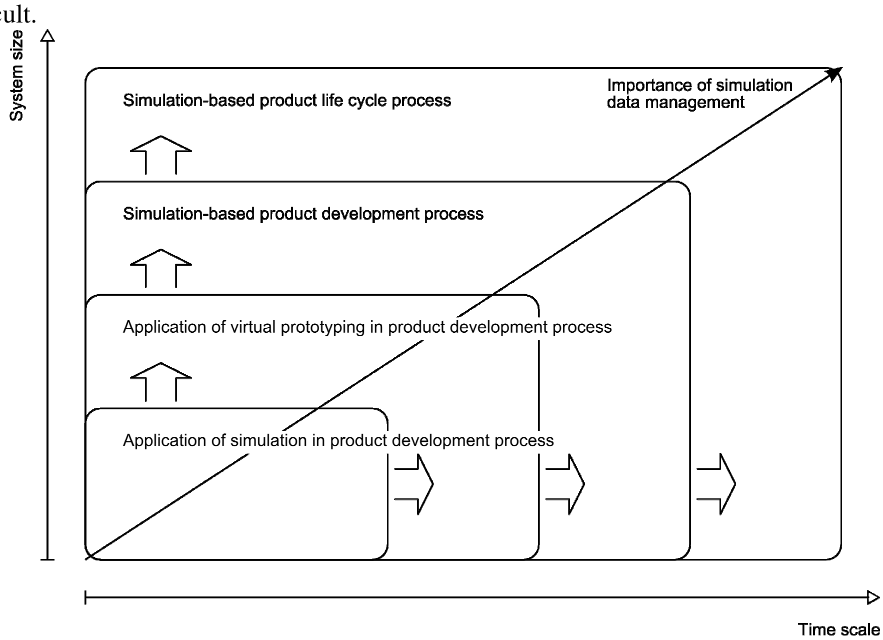

Figure 2. Four levels of the application of computational methods in product process.

A straightforward solution for the architecture for managing product data, including modelling and simulation data is to use a common database for the whole organisation involved in the product process. This enables everyone in the process the access to the up-to-date data and provides centralised version control for the data. In common database architecture, the selection of the database technology may become crucial for the flexibility and efficiency of the system. The modelling and simulation data of different engineering disciplines is usually diverse what comes to the data models and the amount of data involved in one simulation. E.g., the modelling data of a finite element method structural analysis includes tabular form data for geometry discretisation, the element mesh, and the overall structure of the model data does not vary much. On the other hand, a multibody system simulation model does not usually contain large tabular data, but the structure of the data is more varying, which is common to all system type of models. According to this, the approach of applying a common database for all the modelling and simulation data requires the database to support all the different data models and forms in the same database. Relational database model has become the dominant in the markets of databases. There are many commercial and open source database implementations that are scalable and reliable enough for even large-scale design data management. The challenge of applying the relational database model for heterogeneous data structures is that the data model of the relational database itself is inflexible. In addition, the modification of the data model for relational database model may become cumbersome for complex data.

Semantic data model has proven to be an interesting approach for managing complex and heterogeneous data in one data model. The data model is based on describing all the data using simple data structures that are flexible to describe different forms of data. The background of applying semantic data model is in the research of knowledge representation, originating to the research in the area of artificial intelligence. Describing knowledge in software application usable form requires the data to be described in formal manner but so that it does not restrict the content of the data or the knowledge. For the low-level data model the subject-predicate-object (the data triple) form has gained popularity. The data triple can be illustrated as a statement of a subject having a property (predicate) that has a value (object). This is depicted in Figure 2.

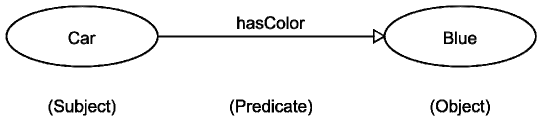

Figure 3. An example of a data triple.

The form of data in semantic data model is often described using ontologies, data describing definitions or application specific vocabularies that define the meaning of the data, together with the structure and connectivity of the data components. Thus, the data triple is aimed to low-level data structure for data nuggets and ontologies in order to add a data description layer to the system. Ontologies can be seen as an analogy to class definitions in object-oriented programming. An example of the application of semantic data representation for simulation data management is the Simantics platform (www.simantics.org). The platform utilises the semantic data model for heterogeneous data management and data mapping inside the database. The software architecture of the Simantics platform is illustrated in Figure 4.

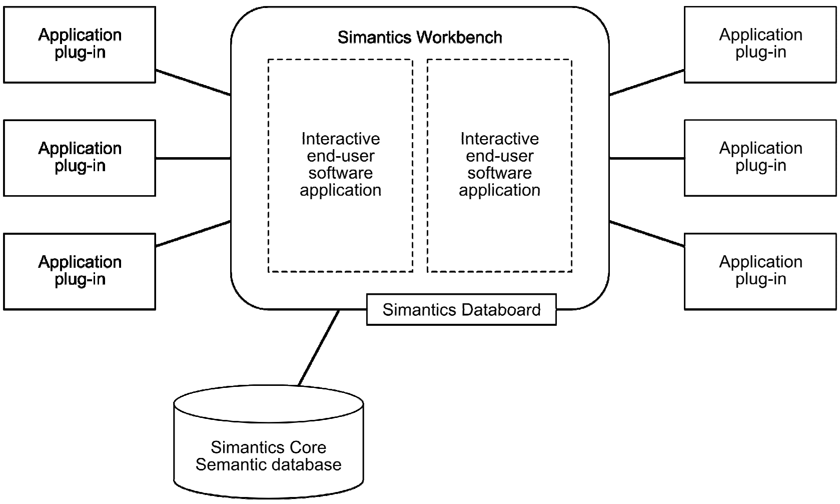

Figure 4. The software architecture of the Simantics platform.

The World Wide Web Consortium (W3C) has been executing a technology development effort for the next generation Web, the Semantic Web, from 1990's. The motivation for the Semantic Web is to utilise more efficiently the information available in the Internet. In the Semantic Web approach, the meaning of the data, its semantics, is connected to the data itself using ontology definitions. This allows the using of software-based reasoning of the data and thus enables improved retrieval of information from the Internet instead of barely raw data. The Semantics Web effort has already provided an extensive set of technologies for semantic data management. These include technologies, such as the Resource Description Framework (RDF) and the Resource Description Framework Schema (RDF-S), which define the low-level data model using data triples and add necessary data types and structures for upper-level data modelling, and the Web Ontology Language (OWL), which provides an ontology modelling language.

The application of semantic data model, including definition of the data using ontologies, enables software-based reasoning and inferring of the data. While the meaning of the data is linked to the data, a software application can define, if the data is valid according to the ontologies, i.e. if the set semantic rules and constraints are true. In a case of simulation model data, this can be used for validating the model data against the modelling domain ontology. In practice this could be used for validating the model while the user is creating or modifying it. While applying Semantic Web technologies, the ontologies, and the semantic rules and constraints are stored using the same low-level data structures and the data itself. This simplifies the data management and application implementation and provides a powerful approach for adding intelligence into the data management system. The semantic approach enables also inferring of new implicit information out of the data, i.e. information that is not explicitly stored into the system but can be inferred from the data using given axioms. An application of semantic reasoning could be an expert system. In simulation data management, an application example of inferring and reasoning is the applying of semantic modelling stencils on design data. The modelling domain (e.g. multibody system simulation) specific semantic constraints and rules are included into the general modelling domain ontology. These constraints and rules are used for general model validation. Applying additional modelling case specific constrains and rules, in the form of additional ontology, on the semantic modelling data, additional modelling restrictions can be set. These could e.g. limit the mass of the parts in an assembly or set limitations to the geometrical dimensions of the system. In traditional modelling tools, e.g. for multibody system simulation, the model validation is coded into the software application and is very difficult to modify by the software application user. The application of semantic data model on multibody system simulation modelling data management is discussed in more detail in [11]. Connecting other product process data into the data management, e.g. in the form of the Semantic Web, would extend the data management system from a storage of pure design data to include other data sources. This provides a method to store knowledge, in the form of ontologies and data relating to these ontologies, into the data. Data combined with the corresponding knowledge would increase the value of the data. This requires other technologies, such as service-oriented architecture (SOA), to be applied.

4 Web technologies for data management

The Semantic Web framework is a result of a common effort from a large number of researchers and industrial partners led by W3C. It facilitates the data to be shared and reused across various applications and organisations (www.w3.org). The Semantic Web framework uses common format for integration and combination of data drawn from different resources. It provides Web pages, databases, services, programs, sensors, and personal devices for the production of data on the Web [12]. The Semantic Web consists of technologies such as Unicode, Uniform Resource Identifier (URI), Extensible Markup Language (XML), XML Schema, RDF Core Model, RDF-S language, OWL, Logic, Proof, and Trust (www.w3.org). Unicode and URI layers ensure that the characters used are identified in the Semantic Web. The XML layer consists of name spaces and schema definitions. The objective of this layer is to support the data exchange for any application developed by any platform, i.e. involving different hardware, operating systems, and programming languages. The RDF core model and RDF schema facilitate the making of statements about objects and define vocabularies that can be connected to URI. The RDF is a recommendation with the objective to standardize the use of definitions and metadata, i.e. presentation of data, information, knowledge, or resources located on the Web. The Ontology vocabulary defines relations among different concepts. Digital signature layer provides support for sending updates to documents. The other parts of the Semantic Web, i.e., Logic, Proof, and Trust are in the experimental phase. They exist only in simple application prototypes that are being developed. Logic layer writes the rules, Proof executes these rules, and Trust evaluates them in a validation process. Except these three, all the other layers have been standardized. The Semantic Web framework definition has to do with the, W3C, significance or vision, which consists of Web linked data. The framework allows people to create data storage on the Web, to build vocabulary, and to write rules for data management (www.w3.org). This is possible and empowered by technologies such as RDF, SPARQL Protocol and RDF Query Language (SPARQL), OWL, and Simple Knowledge Organization System (SKOS).There are among other things five basic characteristics of the current Semantic Web, which need to be followed to make the efforts of the Semantic Web possible (www.w3.org). These are the linked data, the vocabularies, the queries, the inference, and the vertical applications. The W3C vision is to have a huge amount of linked data (Data) in the Web. The data is used by various users and organisations. However, for this vision to be real the data needs to be available in the net in a standard format, reachable and manageable by Semantic Web tools. The W3C provides various technologies such as RDF, Gleaning Resource Descriptions from Dialects of Languages (GRDDL), the Protocol for Web Description Resources (POWDER), Resource Description Framework in Attributes (RDFa), the upcoming RDB to RDF Mapping Language (R2RML), Rule Interchange Format (RIF), SPARQL, etc. to get access to the data. The vocabularies (Ontologies) support the data integration when ambiguities such as terms used in different data sets or when new information and/or knowledge lead to the discovery of new relationships. The role of the query in the Semantic Web is based on the use of SPARQL, which provides the extraction of complex information (i.e., existing resource references and their relationships) which are returned, for example, in a table format. The result of the query can be incorporated into another Web page through the use of SPARQL, which provides a powerful tool to build search engines that include data stemming from the Semantic Web. The inference engine on the Semantic Web provides possibilities to discover new relationships. This improves the quality of the data integration, since it supports the discovering of new relationships, the possibility to automatically analyse the content of data, or managing knowledge on the Web in general. It provides also important techniques to discover inconsistencies in the (integrated) data. Finally the vertical applications mean the generic application areas, specific communities etc. that investigate on how W3C technologies, i.e. Semantic Web technologies can support various operations, improve efficiency, increase the user experience etc. The vertical applications work with for example the second generation languages such as the OWL2 or SPARQL version 1.1, which has benefited from the feedback provided by these vertical applications, i.e. these groups provide valuable feedback on the technologies themselves.

5 Web services

The W3C defines the Web Services (WS) as being software designed to support interoperability between distributed applications over a network (www.w3.org). The WS consists of technologies such as Hypertext Transfer Protocol (HTTP), XML, Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL), SPARQL, and others. The SOAP uses HTTP to transport its messages. The WS provides the system with integration possibilities. Java Sun explains WS as being an application that uses open, XML standards, which use transport protocols to exchange the data with its various clients (java.sun.com). The WS consists basically of three components. These are the XML, utilised in the different layers of the WS, the second is a soap listener, which packages, sends, and receives messages over the Internet with HTTP and Transmission Control Protocol/Internet Protocol (TCP/IP). The code that the client machine uses to read the WS messages is described by WSDL, which is the third component. A WS-agent is software that acts on behalf of a person or organization. The WS agent can request and perform zero or more services (www.w3.org). WS is an abstract notion that must be implemented by a concrete agent. The agent sends and receives messages, and becomes in this way a means to offer and provide the WS. The provider entity, in this case a person or organization, permits an agent to perform a particular service and a requester entity, i.e. a person or organization uses the WS. This is done through a requester agent, which facilitates the exchange of messages with the provider agent. In most of the cases the requester agent initiates the exchange. When a WS is requested, in the first step, the requester and provider agent get to know each other. In the second step the requester and provider entities, i.e. agents agree on the description and semantics to be used in their interaction. In the third step, they use the descriptions and semantics. In the fourth step, the requester and provider entities (agents) interact with each other .i.e. they send and exchange their messages on the enquiry.

6 Conclusion

The capability of carrying out PLCS has raised increasing interest due to a number of reasons. Especially companies are trying to improve their design process and also increase their role in providing services for their products and thus become less sensitive to changes in the market. In spite the interest it seems that the capability of carrying out PLCS today has not really reached a high level. It would seem that the biggest obstacle is the lack of reliable data for simulation. The problem is that companies have data but this data is scattered between numerous programs and tools that are used for different purposes and that it is not easily transferred between these systems. It is believed that semantic data structures can help and that the software simulation of the product lifecycle has become important since they give solution for the complexity of decision-making. This together with the developments of the Web technologies such as the Semantic Web and the Web services provide new possibilities to integrate heterogonous data as well as distributed applications, which provide possibilities to achieve the full simulation of entire enterprises.

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Chapter 9
PLM Maturity

Trends in Technology and their Possible Implications on PLM: Looking Towards 2020

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Abstract: Engineering companies within the High Value Low Volume (HVLV) industry are facing ever-increasing challenges due to the shift towards Product Service Systems (PSSs), and the inclusion of Corporate Social Responsibilities (CSRs) and environmental legislation into their business strategy. Addressing these challenges requires a fundamental understanding of data and information across the entire Product Lifecycle and there is a concern as to whether the current systems for capturing and managing data and information across the product lifecycle can provide the learning and knowledge necessary.

To begin to understand this concern, the paper explores the current state-of-the-art research in applying Knowledge Discovery and discusses their capabilities and limitations with respect to the product lifecycle. The paper then looks towards 2020 and considers emerging ICT technologies and their possible implications on PLM.

Keyword: Product Lifecycle, Knowledge Discovery, Emerging Technology, Cloud Computing

1 Introduction

Three clear trends have emerged within the business strategies of companies within the High Value Low Volume industry over the past decade – i) the inception of Product Service Systems (PSSs) [1], ii) the need to display increasing Corporate Social Responsibility (CSR) [2] and iii) the adherence to stricter environmental legislation [3]. Brief descriptions of these trends are now detailed, alongside the challenges they bring. The importance of knowledge discovery and accessibility of the data and information from the product lifecycle to aid in meeting these challenges is then discussed, followed by a summary of the current capabilities and adoption of Product Lifecycle Management (PLM) systems within industry. After providing this background, the paper explores the current state-of-the-art research in Knowledge Discovery (KD) techniques and their application over the product lifecycle, followed by discussion of the current capabilities and limitations of their adoption into the Product Lifecycle. The paper then looks towards 2020 and considers emerging technologies and their possible implications on PLM.

1.1 The Three Trends

The introduction of Product Service Systems (PSSs) has led to a paradigm shift in business strategy. The emphasis is no longer on the 'sale of the product'; rather it is the 'sale of use' of the product [1]. Rolls-Royces' 'Power by the Hour' is one such interpretation of a PSS. The benefits of introducing such a strategy has been the introduction of a more stable cash flow and therefore enables the company to better manage their finances [4]. The adoption of such a strategy places greater importance on the in-service performance of the product.

As defined by [2], Corporate Social Responsibility (CSR) goes 'beyond the interests of the firm and that, which is required by law', and covers the steps taken by companies to meet requirements brought about by pressures from customers, employees, suppliers, community groups, governments and shareholders. CSR may not provide a quantifiable financial benefit, however it is seen as critical to competitive advantage because of the inception of PSSs. These contractual agreements often span a number of years and are often large revenues streams, and thus these contracts are important to company success. Therefore, the challenges faced by the company from CSR will continually change due to external drivers.

The issue of in-service emissions has seen constant new aims for decreasing the amount of greenhouse gasses and other pollutants. The introduction of the voluntary European Eco-Management and Audit Scheme (EMAS) and Take-Back legislation in America, are examples of the push by governments to see companies take into account the environmental impact of their products over the entire product lifecycle [3]. This has been further enforced by public and customer opinion wishing to see a decrease in the environmental impact of HVLV products.

1.2 The Importance of Data and Information and use of Knowledge Discovery Techniques

HVLV products generate huge amounts of data and information throughout their lifecycle, typically 100,000s files and records ([5] covered a portion of a shared network drive which contained 38,500 files) and terabytes of in-service data (one flight can amount to a 1Gb file [6]). It can be seen that with such a large store of data and information, there are potential difficulties in accessing and retrieving the information required. [7] notes that design engineers can spend up to 30% of their time searching for information. However, the importance of having the right data and information has been shown by interviews with representatives of a HVLV company, which concluded that they believe knowledge and information management is essential for better decision making [8]. Productivity has seen to increase with improved data and information flow [9]; however, currently the cost of finding the useful information may be inhibiting the use of product lifecycle data and information [10].

Contrary to the title, Knowledge Discovery (KD) techniques do not generate knowledge *per se*. The aim of such techniques is to analyse large datasets and present the results in a condensed and easy to visualise manner. This enables the engineer to interrogate/investigate datasets to reveal trends/patterns [11] thereby improving their understanding and supporting the potential for knowledge elicitation. Example techniques include the use of statistical analysis, cluster analysis, neural networks and fuzzy logic.

1.3 Current Capabilities and Adoption of PLM

PLM systems are known as the product information backbone for companies and are in place to enable the integration of people, data, processes and business systems. In essence, PLM is the all-encompassing term for the management of data and information concerning the product, throughout its entire lifecycle [12]. Although, PLM software does have the capability of achieving this goal of managing the whole product lifecycle data and information management, [13-15] has indicated that PLM systems are still being used as extensions to Product Data Management (PDM) systems. PDM systems being the systems that used to manage the product data during the design development stages, namely CAD files. Adoption and integration of PLM systems across all phases of the product lifecycle is still a necessity, however it has been hindered by competing systems (e.g. Enterprise Resource Planning), the variety of formats by which data and information is generated and the need to understand the requirements of engineers across the entire lifecycle. [16] provides an example of the varying requirements for data and information between engineers within design.

It is clear that the HVLV industry has seen significant shifts in ethos, which has resulted in new challenges. This paper now investigates the current state-of-the-art in Knowledge Discovery (KD) techniques, to understand their current capabilities and limitations. Looking towards 2020, this paper then identifies key emerging technologies and their potential impact on PLM as well as the barriers for their adoption.

2 Methodology

A comprehensive literature review, similar in approach to [1], has been conducted to identify the state-of-the-art research concerning Knowledge Discovery (KD) techniques in the context of the product lifecycle. The studies have been mapped onto a generalised model of the product lifecycle, alongside discussion of the current capabilities and limitations to the inception of these techniques within industry. It is conceded that such is the size of the space being investigated, not all applications of KD within engineering will be highlighted. However, review papers have been the focus of the search in an attempt to cover as much of the space as possible. Looking towards 2020, emergent technology trends have been uncovered through review of the literature, Gartners' emerging technologies market research, emerging trends in trade magazines, and interviews with technologists and futurologists in the popular and specialist media. This understanding is used to reflect upon the implications of the identified technologies on PLM and KD capability.

3 State-of-the-Art Knowledge Discovery Technologies

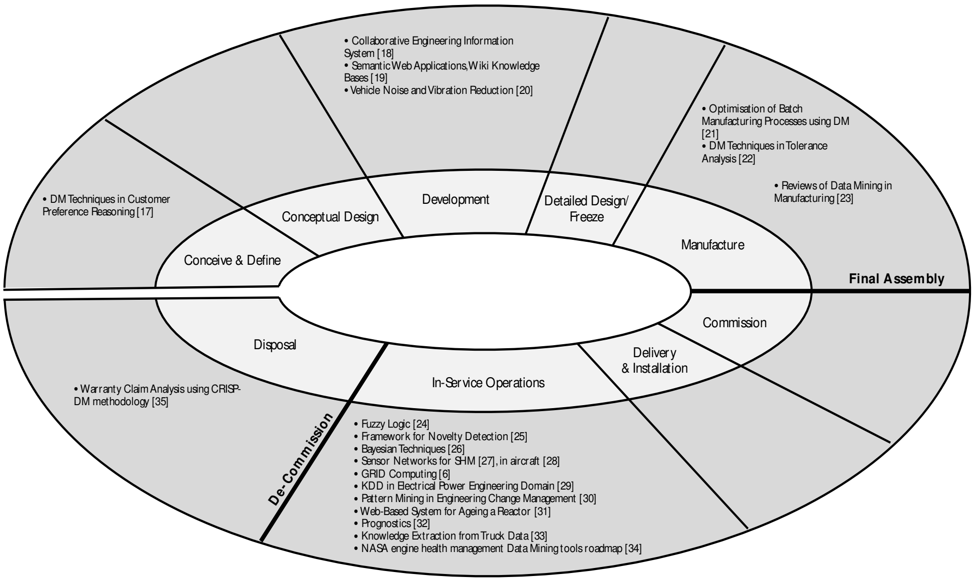

Figure 1 State-of-the-Art Knowledge Discovery Techniques over the Product Lifecycle

Following the literature review, the state-of-the-art KD research has been mapped onto a generalised Product Lifecycle (Figure 1) and it can be seen that the majority of KD techniques have focused on the utilisation of in-service data and information. It is argued that this has been due to the ability to directly associate cost savings to a particular research project if successful. For example, in-service aircraft data has seen high activity in the use of KD techniques as the application of these techniques to remove unnecessary maintenance can see direct cost avoidance benefits [26].[1]

Looking at the design phase of the product lifecycle, most KD studies have focused upon text mining and semantics, due to the often less formal and unstructured nature of the data and information flow. The aims of applying KD have been to provide the design engineers with the right information, be it from an external source (customer preferences) or internal source (knowledge bases, engineering process) in an easy to absorb and concise manner. Moving to manufacture (and in particular in-service,) the KD techniques utilised are often based upon numerical data and where an cost reduction exercise has been undertaken, whereby a solution has been sought through the use of a KD technique on particular data streams. Through this methodology, the use of KD techniques has often met their objectives, although in most instances the authors have commented that the solutions are very specialised and therefore non-transferable [25].

Considering the SOTA KD within engineering literature, a clear trend has emerged for engineering research to take a reductionist approach to using KD techniques on engineering data and information. This may be due to the need for collaboration within

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[1] For the purpose of this paper, the focus is upon the use of KD techniques across the Product Lifecycle and therefore detailed descriptions of the techniques are not discussed

industry and thus business cases/objectives/aims have to be made. However, it is argued that a hybrid exploratory data analysis/reductionist approach may yield best results from engineering data and information [36]. This approach leaves it up to the researcher to explore the various data and information streams available using a variety of formats based upon his/her own experience and knowledge to discover new and interesting information to be fed back to engineers. How emerging technologies may influence this is now discussed.

4 Future Technologies and Possible Implications

From discussion of the state-of-the-art research concerning methods for KD within engineering, this paper turns its attention to the technologies maturing by 2020, alongside reflection on their possible implications on PLM and how they may enable improved data and information flow, which is a current limiting factor for KD. Review of technology analyst Gartner's hype cycle, trade magazines and interviews with key technologists and futurologists in the popular and specialist media reveals eight key technologies that will have a significant impact. These technologies were chosen because of their current high level of interest within all the sources and that are seen to be the key enablers for successive technologies to build upon. Brief descriptions of each technology and its possible implications of PLM are now discussed.

4.1 Cloud Computing

The largest trend, which is seen by many as the keystone through which all new technologies will interact and communicate, is cloud computing. This is the idea that a distributed set of servers and data warehouses communicating through the Internet and Local Area Networks (LAN) will provide all the data storage and computing power required for an individual or organisation. With Gartner's hype cycle [37] and many ICT companies (e.g. Microsoft and Google) promoting cloud computing, it can be seen that the technology is maturing rapidly. The key enabler for cloud computing has been the rise of high-speed Internet access, the need to address the environmental impact of computing and to reduce ICT capital expenditure by companies [38].

For example, Amazon's EC2 computing network [39] is designed to aid scientific computation and is an example of the computing power made available through a cloud computing architecture. Dropbox [40] is one example of cloud computing providing a data storage medium, whereby users can access their files stored in the cloud from wherever they wish. The implication of cloud computing has already been seen within engineering companies; particularly in Small Medium Enterprises (SMEs) who utilise Saleforce's cloud-based CRM [41]. It has been an advantage for SMEs in particular due to the reduction in capital expenditure and access to software capabilities previously only available within global engineering companies. In the case of larger organisations, it is argued that a shift towards private clouds will take place. This enables the company to fully utilise the current ICT infrastructure at their disposal and to maintain ownership of the data and information they generate. The benefits for an engineer will be the ability to easily access the data and information they require and to perform computationally intensive tasks from a device of their choosing, in a place of their choosing.

4.2 SaaS, PaaS, IaaS

Software/Product/Infrastructure as a Service are availability and demand based technology models where consumers access and use up-to-date software through subscription/'pay-as-you-go' methods. As HVLV industries are moving to PSSs to aid the cash-flow through the company it can be viewed that a service based expenditure scheme could further aid a more consistent cash flow. PaaS and IaaS aim at providing the equipment necessary to maintain and update the ICT infrastructure of the company thus removing the need for IT specialists within the company itself. SaaS provides the availability of a piece of software/application to perform a particular task [e.g. 42]. The user/company can be charged in varying formats such as usage or monthly subscriptions [43]. SaaS is often the intermediary between the cloud environment and the user. Spotify is one such example [44] and Microsoft has also begun trials in developing SaaS with their Office software [45].

Software is used in varying amounts and at varying times during the course of the product lifecycle. SaaS philosophies could aid in the better management of expenditure based on software use. An example of the service theory would be the use of CAD software. CAD software use during product development is extremely high, however once manufacture begins the use of such software is reduced. SaaS would charge heavily during the development and the costs would significantly reduce after this period (although the availability is maintained).

4.3 Interaction and Visualisation

The ability to interact with and visualise, data and information has increased significantly over the past decade and is seen as a continually growing trend, especially with the move to cloud computing and the requirement to analyse the ever-increasing amounts of data and information stored within them. Multi-touch touchscreen is now becoming commonplace and the recent introduction of Microsoft's Kinect controller (which enables users movements to be tracked and used to interact and control characters on the Xbox 360 [46]) shows the trend of natural motion interaction and is set to continually mature over the next 10 years. Bill Gates calls this move, the 'natural user interface' [47]. In addition, there are many innovative methods and technologies being developed to aid the visualisation of data and information (see, for example, [48]).

These trends could have significant implications on how engineers of 2020 will be able to interact with and visualise engineering data and information. Visualisation techniques will develop further to handle high-dimensional data and information from different viewpoints (for example, document, geometrical, product and contextual centricities), users will be able to view this through the use of holograms and interact by the use of hand gestures and voice control. An example, would be the viewing of a hologram of the product using SaaS and the user interacting with the object, highlighting areas of interest and the software will retrieve information on that part from the cloud. These technologies would significantly increase interaction and collaboration during meetings compared to conventional presentations.

4.4 Ubiquitous Computing

The term ubiquitous computing denotes the continual trend towards networked computing anywhere, anytime and on any system the user wishes and has contributed to the rise of social networking and wiki's. Social networking has enabled a user to access their own profile, contacts, photos and a multitude of other media through any system the user wishes, be it, a phone, PC or tablet. The introduction of Wi-Fi, 3G and high-speed broadband has enabled these devices to be constantly connected and the trend is for the speed of such connections and the number of mobile devices to increase.

Coupling this technology with cloud computing, SaaS and Open source will enable an engineer to be able to access the data and information he/she wishes from whatever device they feel is most appropriate for their work. The work environment may significantly change due to power of connectivity. Mobility will enable engineering teams to change due to the skill requirements of the project and desk ownership will become less important as any device the engineer uses will contain all the information and settings they use as it is stored in the cloud environment. Also, the ability to work from home and communicate via Internet chat, messages and/or video conferencing will continue to improve.

4.5 Autonomous Distributed Sensor Networks

The connectivity, networking ability and sensor technology of equipment is ever increasing and is seen as a new exciting source for data and information. For example, the aggregation of sensor data from all the cars across the world could provide a highly accurate forecast of weather fronts and even air quality in developed countries.

The implication for PLM is that the information on the usage of a product could greatly aid the development of next generation products. However it is critical that this information be easily accessible, so that analytical methods can be developed to enable sense-making of these datasets. An example of an engineering application is the use of an aero engine sensor data to understand how the product is used in-service, how it performed and also model the air conditions for flights across the world.

4.6 Embedded Awareness

Embedded awareness has been used for the term given to a product that has the capability to inform the user on it specifications, functions, history and other relevant information pertaining to its condition. The idea has been around for a number of years. For example, by using the product name/serial codes in a Google search, the user will be provided with more information on the product. RFID technology has grown in maturity over the past decade and is now being placed in many parts and products [49, 50]. This has been mainly used as an identifier for traceability through manufacturing systems.

Looking towards 2020, embedded awareness will become much more interactive and informative. Cloud computing, alongside SaaS and the development of new visualisation and interface technologies could lead to engineers being able to scan the tag of the product and to visualise a 3-D representation of the product alongside the specifications, performance graphs and history of the product. The possibilities vary according to the product, however the key point to be made is the product-centric manner of how the data is presented to the engineer from scanning the product itself. This may, for example, enable increased interactivity during maintenance, redesign or disposal.

4.7 Open Source/Standards

More of a philosophy than a technology, ‘open sourcing’ has been key to successful development of social networking sites, wikis and much other software, such as Open Office [51]. Open standards also allow software to be created or modified to satisfy the needs of particular groups.

The implication upon PLM is the consideration of software requirements for a company. Opensource enables the development of software tailored specific to the required needs and is a low initial investment due the availability of source code and development kits. However, the cost in maintaining the software capability will remain within the company. SaaS may not meet all the requirements, as it has to maintain generality to be incorporated across industries, however, software capability is provided within the agreement. It can be argued that SaaS will provide the software critical to the operations of the company and Opensource will be used for smaller, group tools unless the capability of the Opensource software provides a significant competitive advantage. Open standards are becoming more commonplace as even software vendors are building their files upon them (e.g. Microsofts new .docx file is based upon the open XML standard). This will (in theory) enable compatibility and accessibility to data and information across different systems.

4.8 Community Tools (wiki, social networking)

Social Networking and Wiki’s have improved the ability to collaborate and share, data and information globally to solve problems. Wikipedia is an example of the use of such a tool to enable people from around the world to use their expertise to aid in defining encyclopaedic entries. The contributions of millions of people have developed a very large store of information of over 17M articles [52]. The CrowdSpirit project aims at providing community based product development using a crowdsourcing approach, whereby the community defines the product specifications [53].

Wikis have already impacted engineering to a small extent. However it is the belief that business processes will shift towards a wiki/social networking appearance in the future and during the transition, there will be formal/informal systems run in a cloud and accessed through SaaS and social network environment. E-mail will become message threads between colleagues, profiles will be the address book and feeds will be projects, with sub-feeds for allocating actions. The feed will contain posts, pictures (with comments), CAD and attached files, which were used. The lead engineer can continually check the feed to see progress and sign off once completed. The feed itself will record the reasoning for the final decision made, however by 2020 it is the view of the authors that a report structure will remain and it would be filed in the formal company system.

4.9 Discussion

As mentioned previously, the current PLM system implementation has evolved incrementally over time to extend the capabilities of PDM and its key focus still remains within the product development phase of the lifecycle. In addition, the review of the state-of-the-art KD literature has shown that most emerging approaches offer some benefit, but limitations on accessibility and retrieval of datasets has limited research to specialist cases and has not generally supported exploratory data analysis approaches.

In order to examine whether this barrier can be alleviated by 2020, a review of emerging trends in technology has been undertaken. Eight key technologies have been revealed and their possible incorporation into future PLM is depicted in Figure 2 and summarised below.

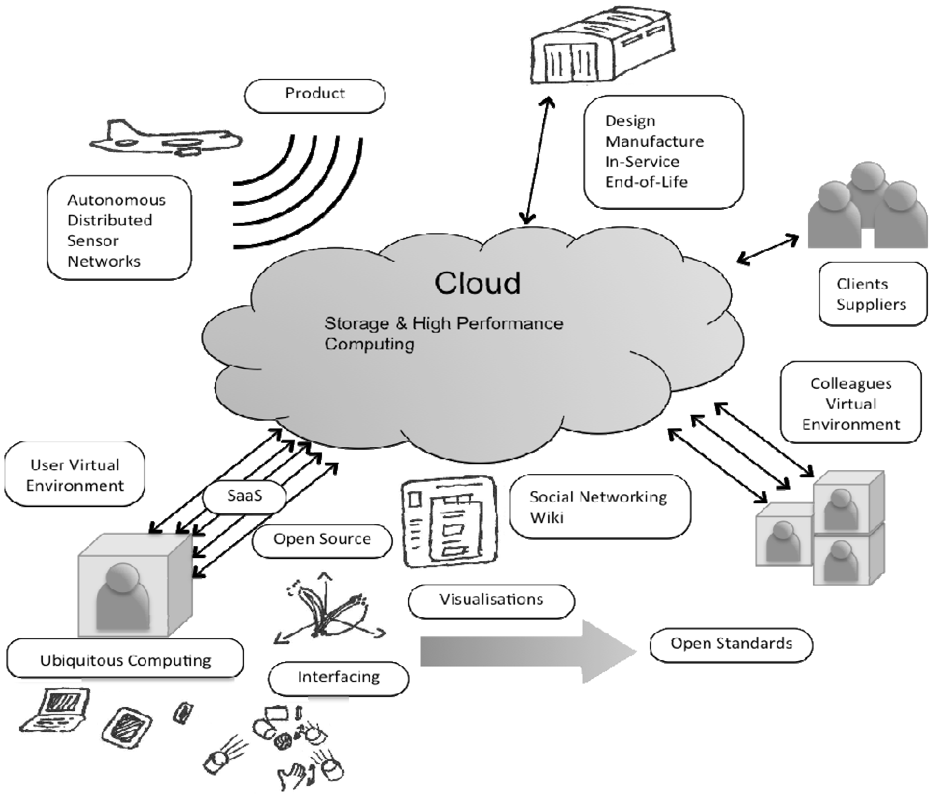

Figure 2 PLM System Scenario in 2020

The cloud is seen to be the backbone of the ICT infrastructure of 2020, where all the data and information is stored from all phases of the product lifecycle and autonomous distributed sensor networks. Focusing on the engineer, SaaS and Social Networking will form the virtual environment by which the user will access the cloud. Ubiquitous computing will allow this to be performed on a device the engineer wishes, with the possibility of novel interface and visualisation techniques being used. The use of Open Standards within SaaS and Social Networking enables the engineer to present and share data and information easily between colleagues. This scenario highlights five key implications that these emergent technologies may have on PLM systems; i) enhance the accessibility and retrieval of data and information across the entire product lifecycle, ii) improve association and linking of data and information within the product lifecycle, iii) provide the opportunity to present and interact with the data and information using novel techniques, iv) introduce informal and formal environments for project work and v) increase the generation and capture of information throughout the product lifecycle.

However, there are many factors that must be considered before these emerging technologies are adopted within industry. The relinquishing of control, ownership (legal/security barriers) and committal to an ICT vendor have to be evaluated. Also, the business models for cloud computing and SaaS are still in their infancy and the actual costs over the entire period of service are unknown. In addition, the emerging technology may have the capability to scale and store theoretically as much information required. However, it does come at a cost and therefore the evaluation and dissemination of 'good/bad' data and information must be considered. The choice of SaaS and use of Open Source software will require thought. For example, Open source may have a less costly introduction and be tailored to the needs of the company, but the cost of supporting the developed software may outweigh the service cost offered by a SaaS. Finally, a clear understanding of how engineers within the company actually use current technology and what data and information they use must be developed to provide the understanding required to allow for the appropriate investment in the interface and visualisation technology needs of the company.

Conclusion

Companies within the High Value Low Volume industry are facing increasing challenges brought about by the shift towards Product Service Systems, the pressures of Corporate Social Responsibility and stricter environmental legislation. It is also argued that current Product Lifecycle Management systems have yet to fulfil their potential in managing fully the engineering data and information generated from the entire product lifecycle.

The literature review of the current state-of-the-art Knowledge Discovery within research presents positive outcomes in most of the studies conducted, however the access and retrieval of data and information, and the approaches taken in research are seen to be limiting factors in the widespread adoption of these techniques within industry.

Looking towards 2020, eight key technology trends have been observed. These are: i) Cloud Computing, ii) SaaS, PaaS, IaaS, iii) Interfacing and Visualisation, iv) Ubiquitous Computing, v) Autonomous Distributed Sensor Networks, vi) Embedded Awareness, vii) Open Source/Standards and viii) Community Tools.

The implications of these emerging technologies on PLM include the potential to i) enhance the accessibility and retrieval of data and information across the product lifecycle, ii) increase the interlinking of data and information across the product lifecycle, iii) provide new opportunities to present and interact with the data and information using novel techniques, iv) harmonise informal and formal environments for project work, and v) increase the completeness of data and information being captured.

However, three key barriers need to be addressed: i) the issues surrounding the relinquishing of control and ownership of the data and information, ii) the need to understand the cost of such an ICT model compared to the current model and iii) the need for a clear understanding of the interface, visual and data/information requirements of engineers working within their various specialisms.

Acknowledgment

The work reported in this paper has been undertaken with support from the Engineering and Physical Sciences Research Council's (EPSRC) Innovative Manufacturing Research Centre at The University of Bath (grant reference EP/E00184X/1)

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Towards future PLM maturity assessment dimensions

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Abstract: Of the many studies on PLM and maturity found in literature, only few discuss maturity or road mapping approaches in the context of PLM. The main objective of using PLM Maturity Assessment is to make the implementation of PLM better approachable and a more carefully planned process, since a significant portion of companies struggles heavily in adoption and implementation of PLM. In our paper, several approaches to PLM Maturity Assessment are discussed. Our aim is to study how maturity levels and dimensions should be redefined to enable companies, even those that are quite advanced today, to define their PLM roadmap for the next five to 10 years.

Keywords: Product lifecycle management, PLM implementation, Maturity models, Maturity assessment

1 Introduction

Product Lifecycle Management (PLM) as business discipline is in full development. Many large companies started implementing PDM (Product Data Management) in the 1990's and have migrated to PLM in the past decade, while many SME's are still in the initial phases of PLM implementation. PLM migration and adoption includes very extensive changes in intra- and inter-organizational practices and requires new types of skills and capabilities, and more than that, even large cultural and strategic changes. Due to the magnitude of this transformation, a controlled and proper PLM implementation can be very challenging in practice, which has been demonstrated by the difficulties companies often face in the adoption of PLM (e.g. [1]). PLM maturity models can be used to make the implementation of PLM better approachable and a more carefully planned process by e.g. comparing the progress in PLM implementation between companies, helping companies to establish their own PLM strategies and goals, as well as helping them to choose the next steps on improving their PLM infrastructure and practices in as efficient and coordinated manner as possible (e.g. [1], [2], [3], [4], [5]). Maturity models can also be used for communicating the planned changes to organizations in an illustrative way.

As the organisations constantly face pressures to obtain and retain competitive advantage, invent and reinvent new products and services, as well as reduce costs and time to market, the need for adoption of and the development of new maturity models will certainly not diminish [6]. In the context of PLM, in the literature there can be found several maturity modelling approaches that are directly or at least quite closely related to the important aspects of PLM implementation. Generally, the concept of PLM maturity assessment is based on the CMM/CMMI (see e.g. Table 1 in Appendix) where maturity is supposed to develop through a set of maturity levels, which can be measured along a set of maturity dimensions. However, there are still various ways to approach the maturity assessment and maturity modelling in practice, and maturity models are developed with various different objectives in mind. To illustrate the current available maturity model approaches we have searched the current literature for maturity approaches, and these approaches have been formed into a table (see Appendix Table 1). As the table shows, the various approaches have their own emphases, and they have been built with slightly different purposes.

For instance the RACE (Readiness Assessment for Concurrent Engineering) distinguishes two aspects of maturity: Process and Technology [7]. For the process aspect it defines the levels Ad Hoc, Repeatable, Characterized, Measured and Optimizing, which are applied on 9 dimensions: Customer Focus, Product Assurance, Leadership, Team formation, Agility, Teams in Operation, Process Focus, Management Systems and Discipline. For the technology aspect it defines the levels Basic, Intermediate and Advanced, for dimensions Application Tools, Communication, Coordination, Information Sharing and Integration. It can be observed that the levels are rather generic, although distinct for the process and the technology aspect. The dimensions are quite specific for product development.

The Batenburg PLM maturity model [1], which we used in previous research [5], applies the four levels Ad hoc, Departmental, Organizational and Inter-organizational on five dimensions: Strategy&Policy, Monitoring&Control, Organisation&Processes, People&Culture and Information Technology. Here the maturity levels are very specific for PLM, since they are based on the idea that PLM has evolved from Engineering Data Management with a departmental scope, through Product Data Management with an organisational scope, to PLM that aims to cover the whole supply chain as well as other parties involved in the product lifecycle.

The two examples of CMM and Batenburg show that the choice of levels and dimensions can be quite different and depends very much on the underlying vision on how the subject area evolves. One problem we found, when applying the Batenburg model, was that the maturity levels are chosen from the PLM evolution until today. As a result, all companies that have made the step from PDM to PLM tend to score the highest level, while it is certainly not true that they have realised the full potential of PLM. Utilizing the current models shown in the table, as well as other existing holistic PLM models, such as Budde's model [8], we try to define a new generic many-dimensional maturity model, which is able to help both starting and even advanced companies to develop their PLM continuously. We also try to take into consideration the main criticisms of a number of Dutch and Finnish companies that have used and tested the Batenburg model in their PLM assessment: in 2010 we tested Batenburg model and found several challenges, for instance several companies found the evaluation scale of the Batenburg model as somewhat problematic, as the measured organisational level of coordination may not tell much about maturity [5]. Second, the model is not able to tell how the next step towards full PLM maturity should be derived from the relative position of a company. In addition, the perspectives of customers and networks were found to be at least partly lacking [5].

The research problem in this paper is: how should maturity levels, and dimensions be redefined in easy-to-use but comprehensive PLM maturity assessment model, to enable companies, even those that are quite advanced today, to define their PLM roadmap for the next five to 10 years. First, we will develop a vision of what kind of developments are to be expected in PLM for the next decade. Then we discuss major criteria for maturity dimensions. Using this, we develop and describe a comprehensive PLM model, and present in more detail suggested maturity dimensions for a PLM maturity model that is easy to use and comprehend.

2 The future of PLM

It is not given to man, and even less scientists, to foretell the future, but finding a parallel development in the past and extrapolating the PLM development according to the same pattern, is an accepted method. The parallel can be found in the development of ERP systems. Both are data based business information systems. The basic principle of both systems it to store data about the actual process characteristics, the actual process state and to record plans for future states. Using those data the different sub processes can be coordinated in much better detail and with much less delay than traditional paper based control systems can do and thus realising better process performance. Both ERP and PLM are not just information systems but business process approaches. ERP goes together with e,g, Supply Chain Logistics, Lean Manufacturing and Six Sigma. PLM comes with Concurrent Engineering, Configuration Management etc.

ERP system started around 1970 when the introduction of hard disks enabled random access programs, as required for processing bills of material. The first MRP systems enabled to model the material flow and machine capacities in a computer program, in order to calculate the optimal loading of machines in a work shop in order to reduce cost. Machine loading became a problem when customers were given choice out of options like colour, so constant flow production lines were no longer possible. The next problem was that manufacturing lead time was several month, so the market demand as input for a planning with a 6 month horizon had to be predicted. MRPII introduced the possibility to also vary capacity over time in order to anticipate seasonal fluctuations in overall demand. The third generation, called ERP extended the capacity planning function to human resource management and integrated it with production planning and financial administration. Because the increasing product variety caused increasing stock levels, the primary argument for ERP investments became the savings on cost for maintaining stocks. Although the primary reason for ERP implementation always had been cost reduction, is appeared, at the end of the 1970's that the main effect of ERP had been:

dramatic reduction of throughput time! Instead of saving a small percentage of cost, the manufacturing lead time had been reduced from typically 6 month to a few days, more than one order of magnitude! This had an enormous impact on business. In the MRP approach the production efficiency relied on long turn demand forecast. Since these forecasts were inaccurate, actual production rarely equalled actual demand. As a result there were shortages of some product types, causing missed sales opportunities, and at the same time large stocks of other product types, that had to be sold with large price reductions or even scrapped. However, the unanticipated result of ERP was that production lead time was smaller than order delivery time, so the company could simply produce just what was actually sold. Not only this resulted in real overall efficiency, but also it meant that the optimal batch size was reduced to one: the manufacturing system was able to produce unlimited product variety.

The past twenty years of PLM history (e.g. [9], [10]) shows remarkable parallels to the history of ERP. The first generation of the systems, called EDM, aimed at organising the storage of CAD-data, in order to reduce engineering cost by saving search time. The second generation, called PDM, aimed at managing not only the storage, but also the processes of creation and application of product data, to reduce the cost of handling and communicating data and to eliminate the cost of errors caused by using wrong versions. The third generation, called PLM, aims at sharing product data between over the whole supply chain and the whole product lifecycle, in order to reduce not only manufacturing cost, but total life cycle cost of products. Looking at the parallel shows that again the focus is mostly on reduction of cost, while the real effect could very well be: dramatic reduction of product development lead time. Just like ERP realised optimal batch size one and manufacturing lead time less than customer order delivery time, the real potential of PLM could be to reduce product development lead time to customer order delivery time and realize optimal repetition factor one: every single product designed and manufactured to customer order. In the current system, mass production prices are only valid for products selected from the catalogue. As soon as the customer has unique requirements, price and delivery time increase with an order of magnitude. The real potential of PLM is to deliver the product to actual customer needs and within the time that the customer is able to foresee his needs. This however, would require dramatic changes in organisational culture and coordination practices.

In the next sections we will discuss what is needed to realise that potential.

3 Creating and selecting suitable maturity dimensions for PLM maturity model

First, the dimensions should be critical for the assessment purpose, in our case PLM maturity assessment and development. Simultaneously, there should not be too many, to make the assessment both easy to understand as a whole, and second, not to make the assessment too heavy for the organization or the assessors. They should reflect the critical success factors of PLM, as well as the main competence areas which allow the planned adoption of PLM. The commonly used basis for assessing maturity in IS are people, processes or objects, or their combination [6].

Generally, the number of organizational ‘foci of assessment’, i.e. the dimensions or viewpoints through which the organizations are examined and evaluated according to the maturity levels, varies from 1 to over 20 [11] being typically around 3–7, depending on the model and its purpose. Concerning the number, no exact rule can be given, but the number should be such that the maturity model is capable to detect relevant differences between companies, and to provide useful instructions for improving the level of maturity. In addition, the results should be easy to understand. Since humans have limited cognitive capacities for memory, attention and perception, it has been suggested that five to seven items [12], generally known as the golden rule of 7, can be considered simultaneously in human decision making, and later research has maintained that the real number is even less, between three to five [13]. Bearing the above in mind, in our case, while we emphasize the easiness of use and the usefulness for continuous development, we aim for the least reasonable amount of dimensions, which would differentiate sufficiently the evaluated companies on the basis of their maturity, and allow the continuous development of PLM maturity.

Furthermore, generally it is thought that in maturity modelling, the advancement in the dimensions should be aligned and coordinated. On the other hand, the relevance of a particular dimension may differ between companies, meaning that it may depend on the companies which dimensions should be most mature. Therefore, ideally, the dimensions, the scales and levels should be selected also to reflect the above principle in the advancement of PLM maturity.

Since maturity models can be both generic or specific (e.g. industry specific) [14], [15], this goal must be taken into consideration when planning and selecting the dimensions. In our case, our goal is to create a maturity model which can be generically applied in PLM development. Thus, the dimensions must be independent of for instance companies' a) industry b) business logic c) product type. Due to the aim of a generic model, the assessed companies and their maturity levels should be at least somewhat comparable according to the dimensions.

Concerning the measurement aspect, ideally the dimensions should also be independent in the respect that for instance maturity in one dimension would not automatically imply maturity also in some of the other dimensions. Naturally, the dimensions, their names and descriptions should be well-defined and similarly understood by all making the assessment. Finally, the dimensions should take into consideration the various model purpose-specific other objectives, such as level of analysis (group/organizational/inter-organizational), assessment method (self-assessment, third-party), etc.[6], [14], [16].

Bearing the above in mind, we first develop and describe a comprehensive PLM model, and thereafter present in more detail suggested maturity dimensions for a PLM maturity model that is easy to use and comprehend, and can be used to define companies' PLM roadmap for the next five to 10 years.

4 Holistic PLM model

Holistic PLM is based on understanding that product lifecycle management is an integrator of tools and technologies that streamlines the flow of information through the various stages of the product lifecycle [9]. According to this understanding IT solutions are not in the first line action. Concept of PLM implies also structural, cross-functional and long-term cooperation between actors in- and outside of a company [1], [17]. Holistic PLM brings together products, services, organizational structures [18], activities, processes, people, skills, IT systems, data, knowledge, techniques, practices and standards [17]. PLM includes planning and control of processes [19]. All these aspects are needed in order to develop and manufacture products which fulfill customer requirements and regulations set by authorities as well as comply with environmental requirements [17].

Grieves [10] emphasises that implementation of PLM requires four aspects to be coordinated: people, processes, practices, and technology. In all these elements the organisation has to make a coordinated plan from where it is today to where its vision is for tomorrow as well as to make coordinated transition, otherwise the whole plan suffers. For example, if IT solutions do not support redesigned processes, the benefit from efficiency will be lost. Or if the right IT software is obtained, but the people are not trained to use it, then people will not use the software effectively.

Batenburg model [1] divides the implementation of PLM into five aspects adding to those above mentioned [10]: strategy and policy, monitoring and control, organisation related to processes, and culture related to people. Often implementation of PLM is focused on processes, project management and information technology. Saaksvuori and Immonen [2] emphasize on processes, structures, IT systems, PLM strategy and people in PLM change management. Budde's model [8] considers that a holistic PLM model based on integrated management approach includes strategy, processes, structures and IT architecture.

The holistic PLM model presented by [8] includes four elements important for development and implementation of PLM, but it leaves aside people and culture aspect. [1] and [10] as well as [2] emphasize also importance of organisational culture and human factor in implementation of PLM, so it is essential that a holistic PLM model includes also fifth element - people and culture.

To be able to plan the implementation of PLM into an organization effectively, it needs to be understood as far more than just another IT system. PLM is a strategic management approach because PLM brings a systematic operational way to develop the company as a whole and it integrates all organizational aspects and levels [1]. Therefore we can find five elements essential for PLM: strategies defining main approaches; operational processes of the value chain; structures of product, knowledge and organization; people and culture, and information technology means.

PLM is a holistic business concept, which guides the usage of all product related information in the organization. Thus, it needs to start with the strategy of an organization, including the product strategy and the knowledge management strategy of the organization, which form the base for a PLM strategy [5].

The chosen strategies define the processes on product development and product delivery. These processes are intertwined, as the same information should be available in different stages of the product lifecycle, and they need to be well integrated to enable the continuous information flow. The processes are supported by PLM structures, such as functional structures and product configuration rules, physical product structures and platforms, and product information structures. Finally, the processes utilize the organizational culture and people as well as the IT architecture as resources. From these, especially the human side of PLM culture and people is often overlooked in the current models of developing the use of PLM. An illustration of this holistic model of PLM is presented in Figure 1 below.

This kind of holistic thinking of PLM builds a good base for developing it. One idea of maturity models is to enable balanced development in different areas concerned. In the

PLM model presented, the most significant areas are identified as the elements of the model.

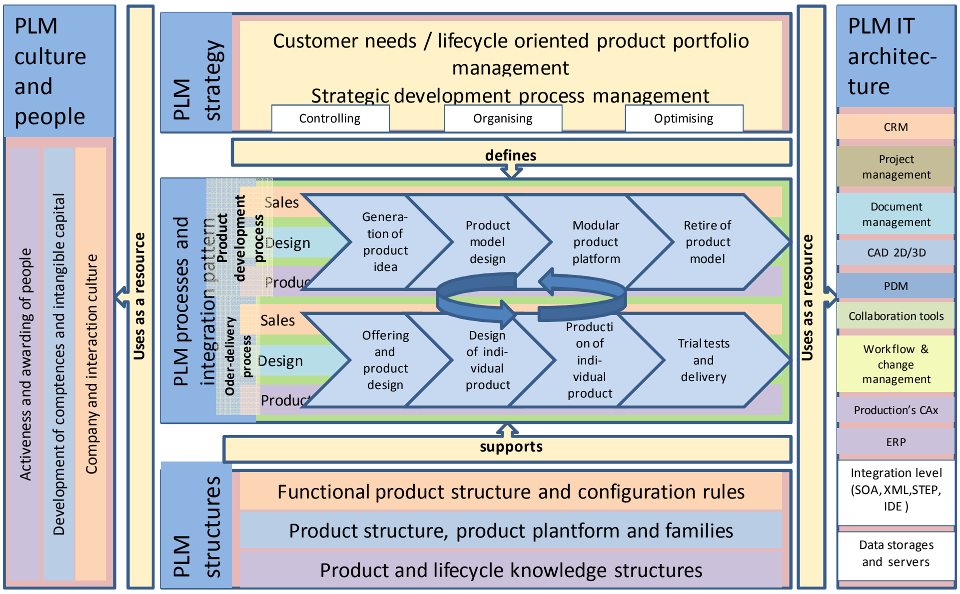

Figure 1 Holistic PLM model

5 Dimensions of PLM maturity assessment

Following the holistic PLM model, the elements can represent the dimensions of PLM maturity assessment. The view of the operating network, customers and partners are included throughout all the dimensions, so they are not regarded as separate dimensions. If the mission of PLM is to deliver products to actual customer needs, some essential capabilities can be derived. We will discuss these in the following.

1. Strategy: Product strategy and PLM strategy are based on business strategy. On the other hand product strategy is determining also knowledge management strategy: customized products for specific needs are related with a person-to-person contact based personalisation strategy and standardized products for common needs are related with IT based codification strategy [20], [21]. The company understands and identifies the customer needs, determines products and how operational processes must run in order to satisfy these needs [8]. For example an engineering company selects to deliver engineer-to-order (ETO) products, which are designed only according to specific customer requirements after placement of an order. This product strategy implies that operational processes are rather different than in those companies, which use e.g. make-to-stock (MTS) or assembly-to-order (ATO) strategies. In many industries the main issue is make products better tailored to customer needs, using available knowledge. However, the increasing complexity of products and process makes that it is impossible for most companies to master all knowledge needed for the

delivering and supporting their products. This implies that they have to outsource non core competence tasks to partner companies that can use the knowledge required for those tasks for more customers and thus maintain that knowledge more efficiently. Issues like supply chain and utilisation of in-house and outside resources are also strategic decisions and are reflecting to all other dimension. However, the most important capability of a manufacturing company is to understand the needs of its customers and this aspect should be reflected in all other dimensions.

2. Process: Processes are the core of PLM [10] and therefore also of the holistic PLM model. Developing generic product models and modules, platforms and product families by creating their definitions are product development processes. Also generic PLM structures and individual products are created in product development processes. Individual products are delivered to customers as a result of delivery processes. Both product development and delivery processes are considered as PLM processes [8], [2]. In order to continuously adapt its capabilities to changing market conditions, the company must have very tight control over the processes that create and validate new knowledge for new product families. PLM processes have an integrating character as they involve main functional units and also partners in the same or in sequent phases of PLM processes [8]. The aim of reengineering of PLM processes is to eliminate internal and external silos, which would hamper information flows.

3. Structures: When, in response to an actual customer order a product is to be designed and delivered in very short time, all design and manufacturing processes must be very predictable, in order to be able to coordinate all those processes with minimal slack. This means that the market offer of a company is no longer its catalogue, but its knowledge configuration that delimits the bandwidth of product variants that can be delivered. Structures are based on the selected product and knowledge management strategies. Structures consist of organisational structures, product structures and information structures. The role of these structures is to support and boost the operational processes. For example, PLM structures include product platforms and families, which allow using product modules, product structures and product knowledge in new order-delivery processes, so supporting re-use of designs and knowledge. Organisational structures, like partner networks, also support use of product modules and knowledge modules and vice versa. The PLM structures are traditionally understood as product platforms, product modules and reference products, but important are also partner networks and knowledge modules. These structures are formed as a result of product development processes. When using these structures together, it is possible to use product platforms efficiently. Such knowledge structures like document templates, module library, item naming system or file directory hierarchy should be developed also before the product development processes. These knowledge structures also support and systemise the PLM processes, product development and order-delivery processes. For Example in engineering companies the PLM structures play important role in systemisation of the order-delivery process of an individual product.

4. Culture and people: Culture and people form intellectual capital, and as a result of their action PLM processes are working and products are delivered to customers. IT systems will have no real effect if the people executing the processes do not have the proper mindset [10] to react as a team to customer needs. Their role is especially important in those companies where each individual product and order is customised according to customer requirements [22]. Recognising and putting this element forward it is possible to develop systematically the intellectual capital of a company. This development would include e.g. training and building of a company culture that motivates and provides awards to a performance that is first of all systematic and only in second hand individual performance and fire fighting. The development of culture and people provides basis for further stable growth of a company as it is obvious that when small companies are growing there would be a limit for growth using personalised, spontaneous and informal operational processes. That is why the companies should make changes also in the company culture according to business and product strategy as well as requirement rising from core business processes.

5. IT-architecture: since PLM as an enabler is IT-driven, the IT architecture of a company and its dynamic adaptation to new technological developments is a necessary condition for realizing the full PLM potential. Information technology is used in running the PLM processes and in up-dating of data and information structures, mainly for creation, acquisition, storing, sharing and application of documented knowledge, but also for collaboration [22]. Many companies which just start to develop their PLM; they first face a situation that the PLM IT architecture consists of many separate IT tools and systems, which most probably are used separately in such a way that any automated integration between different tools and systems does not exist [2]. In this way the company identifies their needs for IT tools and existing ones based on a principle that the role of IT is to support the operations of PLM processes. It might be that small companies face a situation where they need to adopt their PLM processes according to the available IT, but predominantly the requirements rising from PLM processes should define IT architecture. Important function of IT tools is also to support collaboration and interaction, not only performance of individual tasks of experts.

6 Maturity measuring scale and levels

The measuring scales in existing maturity models such as the PLMIG model, CMM, RACE, Batenburg vary from relative to absolute (depending on whether the result of the evaluation is expressed as a comparison, or as a fixed state) and from one to many dimensions, as well as from detailed descriptions of each level to short factual explanations. In this paper, measuring the maturity of the organization on each of the five dimensions of the model is based on a relative scale from initial level to ideal level. For the moment, we have defined both ends of the measuring scale but not described each of the levels between them. The measurement scale is defined from a point of view of one organization, but could as well be expanded and applied to a network of partner organizations taking part in the PLM processes in different stages of the lifecycle.

In the strategy dimension, a typical situation in the initial state is that no PLM strategy has been defined, and the product strategy or even the corporate strategy and vision are unclear, and the customer order is all the company knows about the customer. In an ideal state, the PLM strategy has been defined and is also communicated to the people and understood by everyone involved in the processes and they know the reason behind every customer need and follow the evolution of those needs during the full product life.

In process dimension, an initial state is an ad hoc process, which has not been defined or shared, but is based on individual knowledge and skills. In an ideal situation, PLM processes are defined, shared and optimized so that they fulfil and support the strategy the organization has chosen, regarding their products, customers, partners etc.

In an initial state of PLM structures, they are not yet defined or at least not in a usable form to the different parties, when in an ideal state the product structures are well defined and allow flexible product configuration.

In people and culture dimension, an initial state is when people do not have a common understanding of PLM and its associated processes, and an ideal state is reached when they share a view on how PLM is executed in the organization. Culture is an issue because new strategies will not work if the people are not aware of the changed rules of the game. In the ERP history it was quite common that specialised staff installed software and processes for complete customer order driven manufacturing, while even 10 years later long term production planning routines were still operational and manufacturing managers were still rewarded for machine load level, even if they produced unsellable products. Maturity on the culture dimension has to do for example with the move from single process step focussed task descriptions to multi-company order focused teams.

IT-architecture seems a difficult dimension to scale. The scale can be defined for example from the initial state of no existing IT-based support to PLM to an ideal state of integrated, possibly automated IT systems to handle product information throughout the lifecycle. This development can be divided into three areas: the improvement in computer processing power, data storage possibilities and communication possibilities, which lead to more effective collaboration.

A summary of these descriptions for each dimension is presented in Table 1 below.

Table 1: Scale of measuring the maturity dimensions from initial state to ideal state

Dimension / state	Initial state	Ideal state
Strategy	not defined	defined, shared
Processes	ad hoc, individual	optimized to support strategy
Structures	not defined	product structures and configuration easily adjustable
People and culture	no shared understanding on PLM	common view on how PLM is executed
IT architecture	no IT support for PLM	integrated product information

7 Discussion and Conclusions

In this paper we propose and discuss a set of maturity dimension that should be able to follow developments in the next decade. The main motive for our research is that current methods have reached a kind of saturation and are not able to follow future developments. Also they lack criteria for factors that are really relevant for PLM. Especially the Structure dimension is missing, while proper structuring is essential for mastering the complexity of future product systems.

The framework still leaves much room for discussion. The dimensions are based on developments that can be observed currently. We propose five dimensions, because more would make it difficult to understand them in a holistic view. We propose 3 'hard' dimensions: Processes, Structure and IT architecture, and 2 'soft' dimensions: Strategy of maturity supposes that there is a strategy towards a future goal. Maturity indicates the progress on that road and helps to define the tactics for the next step. Culture is essential since it is the fuel for progress. If people are not motivated to support the strategy, little will change.

In our early discussions we had Customer Needs as a separate dimension, because meeting customer needs is the ideal of PLM. Yet we dropped it as a separate dimension, because it is strongly related to all other dimensions. This means that customer intimacy must be part of the strategy. Customers must be integrated in processes. Customer Needs must be defined and maintained in structures. Customer focus must be part of the culture. Even customers must be integrated in the IT architecture.

A last remark is that we are not sure that the dimensions are orthogonal. For instance there may be strong relationships between structure and processes. This is an issue for future research. Our main goal is however to define levels for each dimension and criteria to measure them. We want to test these criteria when conduction assessments with the Batenburg method, by asking questions on new criteria and having open discussion on their understanding.

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APPENDIX

Table 1: PLM- related maturity models and their comparison

	Batenburg model [1]	Sääksvuori-Immonen model [2]	PLMIG model [3]	RACE (de Graaf, 1996) [7]	Product development collaboration maturity model [14]
Target area	PLM	PDM/PLM	PLM	Concurrent Engineering	Inter-organizational PD collaboration
Dissemina-tion	Open	Open	Exclusive / restricted	Open	Open
Audience	Academia / management	Academia / management	Management / clients	Academia / management	Academia / management
Dimensions	5 dimensions (strategy and policy, management and control, organization and processes, people and culture and information technology)	1 dimension (PLM generic maturity)	5 dimensions (Data, people, processes, technology and knowledge)	16 dimensions Two-fold: Processes and Information technology	7 dimensions (collaboration strategy, development process, system design/task portioning, partner selection, getting started, partnership management, partnership development)
Level descriptions	4: Likert scale: ad hoc (0) to interorganizati o-nal (4) level	5: Initial / ad-hoc (1) to optimized (5)	5: Initial / ad-hoc (1) to optimized (5)	Processes 5: Initial / ad-hoc (1) to optimized (5) Information technology 3 basic, Intermediate and Advanced	4: Starting to high-quality (various descriptions)
Staged / Continuous	Continuous (no predefined order of development)	Staged (predefined order of development)	Staged (predefined order of development)	Staged (predefined order of development)	Staged (predefined order of development)
Continuous improvement means	Balance between dimensions; identification of gaps; always improve lowest level Benchmarking to others	Process improvement is continuous; Defined criteria for reaching each level of development, evolving from level 1 to 5 as PLM maturity grows	Advice to next steps Identification of gaps; coordination of development of dimensions	Improve what is most important for your own company specifically	The approach presents a structure on which to represent important aspects of collaborative behavior (good/not-so-good practices), in order to stimulate discussion and provide guidance; checklist –like frameworks
Restrictions	Emphasizes improvement towards interorganizati o-nal level	Focus much in automation of processes by IT Does not con-sider specifical-ly the coor-dination of different mana-gement foci	Structure-based approach: industry- or even company-specific evaluation questions	No specific PLM or information management focus	No specific PLM or information management focus

Researching PLM process in industry– Case of Benchmarking ECM

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Abstract: The objective of this paper is to study PLM research in industry with the focus on research methods. In the paper, PLM research is being studied with the literature review. Benchmarking is presented as a suitable method for researching the adoption of PLM processes in industry. A case study utilizing benchmarking on the engineering change management (ECM) process in a company is presented. It is concluded that the different methods provide results, whose reliability is dependent on the level of detail in the study. Surveys and brief interviews are suitable for generating an overview, but benchmarking and case studies provide more reliable evidence on the adoption of the details of PLM processes

Keywords : Benchmarking, PLM processes, research methods

1 Introduction

The paper presents an analysis of the interviews, benchmarking site visit and a case study on the adoption of PLM process in a company. The reported study is a part of larger research, where seven companies and three research institutes are collaborating. The objectives of four research (the aim of this paper in brackets) are twofold, because our research questions are

a) How PLM processes (in this paper: Engineering Change Management) are being approached and utilized in manufacturing companies (in this paper: one company) with high variety products and global operations?

b) How reliable are the methods utilized in the process of enhancing the knowledge on the first question?

In other words, our aim is to assess the adoption of PLM processes and the deployment of PDM functionalities in a set of globally operating manufacturing companies and to evaluate the validity of consequent conclusions. Therefore, our results and conclusions cover two different matters, i.e. on the topic per se and the method of studying the topic.

The research proposes the adoption of PLM is an ongoing task that hardly ever finishes in a company. Even the applied functionalities of PLM systems are being re-considered and their deployment is being altered. We claim that the set of brief interviews can provide an overview on a wide area of topics in a set of companies, while a well prepared benchmarking event provides a more in depth view on a selected company and a focused functionality. Moreover, a case study can penetrate even closer to the adoption of a specific PLM functionality in an organization. Also, the different methods can provide different (and even contradictory) results. For a researcher the set of research methods can provide a continuum of means for framing and sharpening his/her view on the deployment of PLM. With a broad framing a rough overview can be generated, but details are lost (or even misinterpreted). Similarly, the focused studies may provide better understanding on details, but to the detriment of an overview.

1.1 Literature overview on the adoption of PLM in industry

Recently, the adoption of PLM has been studied by a number of researchers in different countries. In the table below, we present a selection of the literature is and compare the purpose, the theory base, the used methodology and the material or the source of information of each paper.

Three papers [Batenburg et al. 2005, Terzi and Garetti 2009, El Kadiri et al. 2009] related the purpose of research in the implementation/deployment, while others had either more generic [Park et al. 2009, Abramovici et al 2010] or specific [Barni et al. 2009] objective. Majority of papers dealt with the benefits and the implementation of PLM systems. Even though the PLM implementation is a business decision and requires the justification of investment, it is peculiar to expect any substantial fact on the benefits in the implementation phase, because the benefits are attained in the utilization. However, two papers [Batenburg et al. 2005, Abramovici et al 2010] addressed the topic of PLM benefit from the utilization perspective.

For constructing a structure that can be held as a theoretical frame of reference, two papers [Batenburg et al. 2005, Abramovici et al 2010] utilized maturity models, such as CMMI [SEI 2010], for addressing the level of PLM usage in a set of companies. Furthermore, Abramovici and Schindler [2010] had used past experience for creating a framework of three topics and their sub-factors, such as key performance indicators in PLM Benefits. Park et al. [2009] utilized a framework developed by a PLM vendor. One paper did not clearly indicate any synthesis of literature, while another relied on the overview on PLM presented by consulting companies. This small set of papers indicates the lack of the theory of PLM.

Most papers had a single research method approach and the presentation of the method was typically quite short. One paper [Batenburg et al. 2005] presented an approach where a set of methods was being utilized. However, the distinctive factor may be the media, which was different in the much longer working paper by [Batenburg et al. 2005] than the other conference papers.

Along with the utilization of different kind of methods, the papers had the varying sets of material. For example, Abramovici and Schindler [2010] utilized a very long experience from past research for studying the trends in PLM. Terzi and Garetti [2009] had selected 37 cases from more than 100 cases for their study. Park et al. [2009] had only four cases whit another kind of a research approach.

Table 1 Results of literature review

Purpose	Theory base	Research method	Source, material	Reference
To "explore the „optimal" deployment strategy for companies".	**Relation model**: PLM Maturity vs. PLM Alignment in organizations	**Group discussions**, questionnaire, clustering and characterizing	23 managers / 23 companies x 3 times (convenient random sample)	[Batenburg et al. 2005]
Design of a survey for investigating the use of specific method in PLC.	**Literature review** on the method and **reference model**	**Classifications** on the business and the method context based on literature	7 companies, but ongoing at the time of the report	[Barni et al. 2009]
The presentation of experience on PLM implementation projects.	**Relation model**: cPDM vs involved business functions	Analysis of large number of **case studies**	37 business case studies on PLM implementation	[Terzi and Garetti 2009]
...impact of means & methods used vs. needs in the deployment of a PLM	-	**Survey** (online questionnaire)	40 respondents / +300 send	[El Kadiri et al. 2009]
... business practices for global market strategy through specific PLM practices	**Framework** based on PTC	**Explanatory reporting** of experiences against selected PLM functionalities and factors	4 selected case studies	[Park et al. 2009]
To "provide valuable information and support guidelines for PLM decision makers"	**Framework**: PLM Maturity PLM Benefits PLM Strategy	**Interview** hypotheses defined as verifiable statements, (accepted or falsified / interviewee), clustering	25 worldwide operating companies / automotive industry / (1999, 2004, 2010)	[Abramovici, Schindler 2010]

From such a brief set of papers it is possible to state that the PLM research has is well integrated to practice, but lacks a common theoretical basis. The used methods and the material vary. Thus, it is viable to analyze what kind of results it is possible to obtain with different methods. Moreover the important question is: how reliable are the results of different methods?

2 Research method and material

Benchmarking is a widely used method in industry [Kyrö 2004, Ahmed&Rafiq 1998, Camp & DeToro 1999]. It is defined as a continuous discovery process and learning experience where the companies are pursuing towards the best practice and superior performance by measuring products, processes, services, or other practices against the industry leaders [Camp 1989]. Benchmarking is executed by comparison in order to find the gaps between the current and the best practice develop solutions to close these gaps, and implement those solutions into the companies‟ practices. Although benchmarking is occasionally called legalized industrial espionage [Lecklin 2002], the purpose is that both participants will give and receive something, i.e. benchmarking is a two way process. [Camp 1989, Camp & DeToro 1999]

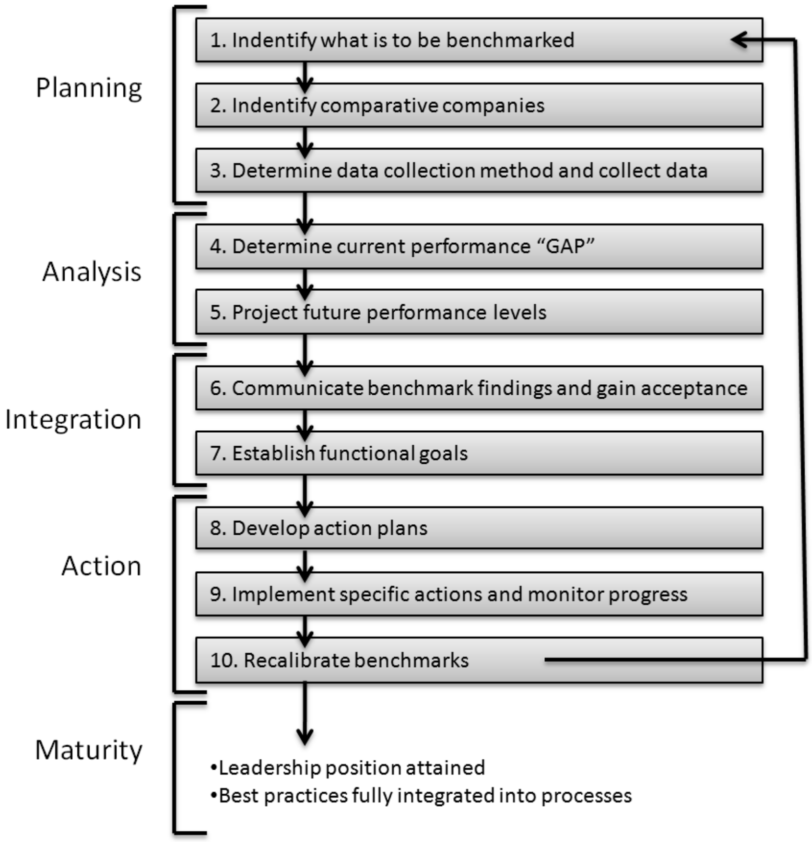

Figure 1 Benchmarking process steps by Camp [1989]

The benchmarking methods vary from case by case. However, some systemized process models have been developed. One of the most commonly cited benchmarking process models (see Figure 1) is the 10-step benchmarking process [Camp 1989] which is also known Xerox‟s benchmarking process steps [Ahmed&Rafiq 1998]. It consists of five phases which are planning, analysis, integration, and action; sometimes the fifth phase is called maturity, which means that the company has attained the leadership position and benchmarking can be finished [Camp 1989, Camp & DeToro 1999]. However, benchmarking should be an ongoing process so it should not stop after one round of the process [Camp 1989; Ahmed&Rafiq 1998; Camp & DeToro 1999].

2.1 Our application of the methodology

In this study, we used the benchmarking as a method of gaining the data of the Product Lifecycle Management in the companies from Finnish industry. The distinct from the Xerox"s process model was that the purpose was to find the best practices among the project companies and utilize the knowledge of the several experts. The focus of the method was on the planning phase and the analysis, i.e. we defined the topic of the benchmarking, chose the comparative companies, made the data collection and identified the gaps. At first, we interviewed the PLM experts of the companies that created the base for the actual benchmarking site visit and determined the topic of the benchmarking. The second round was the actual benchmarking site visit to one of the company of the project. Finally, we compared the results with the previous case study in order to define the validity of the results and the research method.

The goal of the interviews was to create an overview of the current practices, and define the challenges and objectives of the company in area of PLM, but also prepare the next step of the project i.e. the benchmarking site visit. The interviews were conducted during a three-hour session with one or two interviewees from the company and two to four interviewers from the research institutes. The interviewees were representatives from the leading positions who had several-year experience of working with PDM, PLM or ERP issues in order to get the extensive description of the past and current situation in the company. The interviewers were researchers and doctoral students from TUT and VTT whose level of knowledge of PLM varied. However, the basic knowledge about PLM was required from the interviewer in order to document the result of the interviews.

The questions were prepared among researchers and they were documented on a form which was sent to the interviewees beforehand by email and by Project Place application (www.projectplace.com). The questions were considering the benchmarking backgrounds, and expectations that the companies had for the benchmarking; the description of the current products, practices, interests, strengths and weaknesses; and the level of the usage of PDM and PLM functions, such as engineering change management (ECM) and product structures.

The answers were documented on the form and reviewed by the companies. The result of the interviews was summarized on a report, which was distributed through the Project place application before the first benchmarking site visit. According to the result, we also defined the benchmarking topics for the site visits. The companies, which assess the strongest on a certain field, were selected to benchmark on these topics.

After the interviews, one of the companies organized the first benchmarking site visit together with researcher institutes. Researchers and doctoral students gathered a list of benchmarking questions under a few topics of the PLM. The question list was delivered to the companies in association with the invitation to the benchmarking site visit in order that the other companies could prepare on the visit by creating questions according to their own interests. The benchmarked company organized the facilities for the benchmarking visit and prepared a presentation about the company and the benchmarking topic.

Several companies participated in the benchmarking event with one to three representatives. The participants were experts of the PLM area or they had worked on the PDM, PLM and/or ERP. The event started with the introduction into the topic and the result of the interviews and the presentations of the company and the benchmarking topic. After the introduction, the benchmarking questions were discussed a topic by a topic and the participants could ask more specific questions or comment on the conversation when necessary.

The benchmarking conversation was documented on record, which was transcribed to a report. The report was delivered to a review to the participants of the benchmarking event. Identified gaps between the companies‟ practices were gathered through feedback which was collected via telephone. The feedback considered comparison between the company and benchmarked company, identified gaps and solution that company had found to these gaps.

3 Case study on applying benchmarking

Case company is a large manufacturer of mainly configurable, business to business products. The volume is therefore limited, but all products are made / assembled to order. One of the case company ́ s strength is PDM-system, which has been for several years the globally accessed. A functionality that has been especially addressed is the engineering change management process in PDM-system. Although company feels that they are in very good level in managing engineering changes they still want to develop the process.

3.1 Focus on ECM process

At the first interview it was told that the whole engineering change management process is going to be changed because of new systems. When managing ECM process globally there are challenges in traceability of changes, managing item versions and scheduling the implementation of the changes. ECM process was taken as a topic of benchmark event, because the company had strength in ECM process and had a motivation to develop it forward. As the result of first interview and interest of other companies the main Benchmarking questions were:

- Which kind of ECM Processes Company has nowadays?
- Why it is going to be changed?
- How it is going to be changed?

In benchmarking site visit the whole ECM process was explained. Process considers changes of items that are already approved for production. It was told that process follows the CMII standard. In general ECM process seemed to be well-defined and working. Engineering change request (ECR) and engineering change notice (ECN) phases are handled in PDM-system (see Figure 2).

ECM process begins with feedback handling, which is made locally to the different systems. In engineering change request (ECR) phase feedback is collected to the PDM-system. Different analyses, like change effect analysis and cost-benefit analysis are made by engineering function. If necessary, a change request may go through engineering change board. If the change request is proven to be feasible, it is changed to a new status that is engineering change order (ECO) and engineering will do the change. When change is ready an engineering change notice (ECN) will be done and finally change will be approved for production.

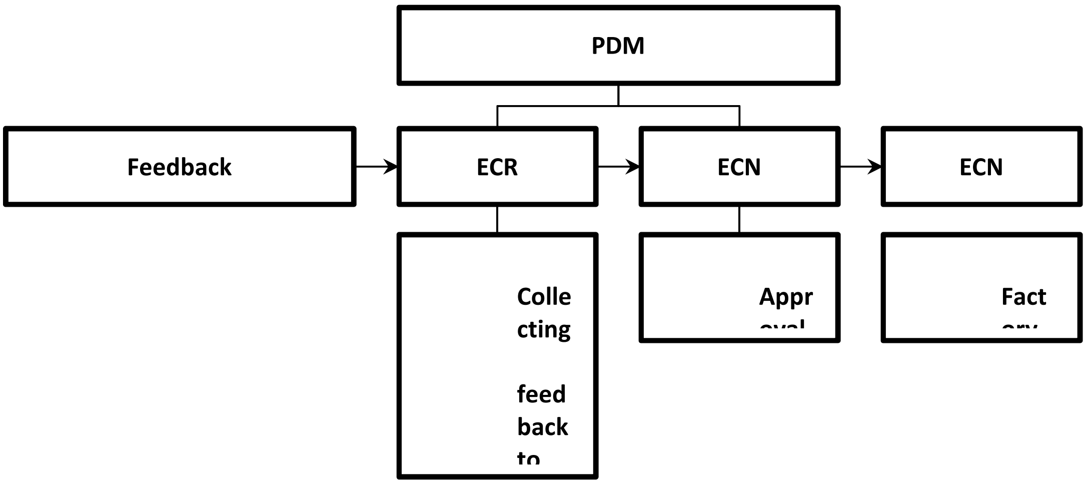

Figure 2 Present ECM process

An interesting point is why the good working process is going to be changed, as we assumed according to our interviews? Our perception of the re-engineering of the ECM process of the case company was not correct. In the benchmarking event it was told that a new phase to the process will be added. The company will include the phase of engineering change implementation (ECI) to the end of ECM process, as the recently implemented ERP-system requires the phase, which will be included to PDM-system. With the ECI it is possible to manage implementation process, schedule implementation of the changes and the whole item history will be traceable, which will enhance the functioning of the process, but no extreme modification will be done to the ECM itself.

A recent case study concerning the ECM process in the same company showed that there are plausible improvements in the whole process. Some of them are little improvements but there really are wishes to change workflow of the process too.

3.2 Summary on the study

Comparison of interview, site visit and case study data are shown in table 2. After the first interview the perception of the interviewers was ECM process was in good level, but it was going to be changed because of new systems. There were also some development needs pointed. After the site visit interviewers‟ perception of the ECM process had not changed. However, the whole process was not going to be changed, but new ERP-systems required the ECI phase to the end of the ECM process. This new phase could also solve those development needs. The case studies indicated there still were tribulations and improvement ideas for the whole process.

We can conclude that the initial interviews gave the interviewers an outlook, which was partially correct and to some extent misleading. The potential reasons for this are that the interviewers‟ understanding and notes were not correct. Also, the interviewee may have emphasized the re-work of the process. However, the communication of details within the short time frame of interviews did not allow concentrating on the one detail of PLM process.

Table 2 Comparison of data (findings)

The first interview	Site Visit	Case study
ECM is in good level	**ECM is in good level**	**ECM could be better**
Whole process will be changed	**Process will get new phase**	**Improvement ideas for whole process**
Development needs exist	**Needs have solution ideas: just implementation**	**Improvement ideas for whole process remain**

In the site visit the preparation and the documentation of the benchmarking event was far better and the focus on the ECM much sharper than in the interviews. Researchers did not rely on the notes and the memory, but the discussions were recorded and later transcribed. This is probably due to a far bigger audience comprising of colleagues from industrial companies. This may have improved the preparation of the participants and lead to corrected understanding of the modification of the ECM process. However, our insight is the most realistic information about the situation in a very clearly marked out PLM process can be attained with an in depth case study. Still, the definite case study typically leaves out an overview on the other PLM processes.

4 Conclusions & Discussion

In this paper we approached the studying of PLM process in industry with a brief literature study, followed by the presentation of benchmarking as a research method comprising of many stages and presenting a case study on one PLM process in a company. The literature review points out that there is versatility of methods for the studying of the topic of PLM in industry and they are used with varying degree of theoretical background.

Moreover, we conclude the different methods are good for different purposes. There is not a universal “one size fits all” method, spanner / a monkey wrench in the toolbox of a PLM researcher. The case of benchmarking ECM suggests that in the initial interviews may give misleading information about the details, such as a singular PLM process. Also, our experience from the feedback round of the report of interviews support this conclusion. Apparently, the surveys and brief interviews, with researcher (as an interviewer) practitioner (as an interviewee) approach may be good in finding the set up of PLM deployment in the national or regional level. However, they may be misleading in the details and therefore methods such as benchmarking events and case studies are better for drilling into details.

The adoption of PLM is recurring process. Due to many reasons, such as new versions of PDM and ERP systems and totally new pieces of software, organizational changes, etc., companies are frequently changing their adoption of PLM. For example, the case company is a forerunner in the adoption of ECM process in Finland, but still it is improving the process. Our findings in the other companies support this conclusion. For example, many of the participants have been in a very good level in the management of variant products, but re-consider their way of managing product structures due to multi-site approach. After all, PLM is a very practice oriented matter, which recalls revisions of the approach in the global competition. Therefore, it is very difficult to compare the level of PLM application in details, because the needs, business contexts and the competitive edges of companies are not uniform.

Acknowledgment

We acknowledge the companies participating and funding the research and the Finnish Funding Agency for Technology and Innovation (Tekes) for funding the research. We would like to thank the fellow researchers in VTT and University of Vaasa for their input in the benchmarking research.

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A conceptual framework to develop assessment models for PLM implementation projects

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Abstract: The adoption of a PLM-oriented approach in large companies, or in a complex supply chain, needs a well-structured plan of change management. Product-Lifecycle-Management may significantly increase the efficiency and effectiveness of enterprise processes but requires cooperation between different actors and product-data information sharing; such interoperability often requires the evolution of organization aspects. This paper aims at presenting a conceptual framework that can support a large company, or a group of companies, in defining the assessment principles on which a PLM implementation project should be based on. Indeed, in the initial stage of a transition to a PLM vision, the process of gathering information assumes a key role in the creation of the knowledge base about the as-is state, specifically with regard to the company awareness of PLM concepts, to the adopted technologies, to the purpose of the project, to any specific requirement, etc. The framework presented here originates from the analysis of the common path towards the implementation of PLM logics at a corporate level by a large group of companies operating in the aerospace & defense industry.

Keywords: product lifecycle management; assessment; standard reference framework; corporate strategy

1 Introduction

Large companies that intend to cooperate with their suppliers/customers in designing, implementing and managing the product through its life cycle need an effective way to adapt their management perspective: an organizational evolution of the company is the necessary requirement to achieve a perfect coordination of begin, middle and end-of-life activities management, i.e. from design, through production, logistics, product support, up to the reuse or disposal of products. Once the benefits on PLM of this new organizational perspective are identified, a series of actions should be undertaken in order to promptly identify the areas of intervention and provide a roadmap for managing the change in the entire company. This evolution should be, however, based on specific guidelines: these can hardly be defined *a priori* and their definition requires the participation of several figures of the organization. The industrial case that inspired the work which is partially described in this paper is related to a large group of companies, operating in the aerospace & defense industry, that agreed on cooperating in defining a common path towards the implementation of PLM logics at corporate level.

2 A standard reference framework as a guideline to start PLM projects in a group of companies

A PLM implementation project needs a strategic commitment to create those favorable conditions to enable the progress of the implementation phases of the project through an initial top-down approach.

When dealing with a group of companies heading towards a PLM vision at a corporate level, a prerequisite for generating a significant participation of the different entities is, surely, an effective management capability, in order to lead the corporations, with motivation, toward a path of change. A strategic commitment can be reached, for example, by creating focus groups coordinated at a central level and composed of the most credited representatives of the companies involved on the PLM project. On top of allowing members to interact and share experiences and solutions, focus groups keep a bottom-up approach and force each entity to be practically involved at least in the first step of the scenario definition. The first outcome of a PLM transition project, at corporate level, should certainly be the definition of guidelines to be used by each company to start specific PLM projects. To this extent, an assessment phase may conveniently represent the initial step in order to define a framework structure, collect all the basic information and create a macro-scenario.

In this sense, three aspects should be considered and properly balanced in order to design an effective development path:

- **Technological issues:** include aspects related to infrastructures, applications and data exchange standards that allow interoperability with customers/suppliers. These elements, often rated as major factors for the success of a PLM project, should however be analyzed coherently with the other elements.
- **Organizational issues:** represent all the elements related to the organization (business processes, roles, involved professionals, etc.), which typically are the most complex aspects to cope with, given the natural attitude of organizations to maintain their *status quo*.
- **Strategic issues:** include the definition of the intervention strategies, budget, benefits, risks and SWOT analyses associated with PLM projects, etc. which allow translating plans into feasible and successful actions. These aspects play a key role in those decision-making processes that determine the successful implementation of PLM within a group of companies.

The process of information gathering must be properly structured in order to provide different levels of detail in the analysis: at the initial inquiry stage, even simple questionnaires can be submitted to individual companies and partners at different organizational levels [13]. This will allow performing an initial assessment in order to understand where to concentrate, considering;

- Process layer
- Integration layer

- Application layer
- Data layer

Subsequently, targeted surveys may specifically investigate certain details among these areas.

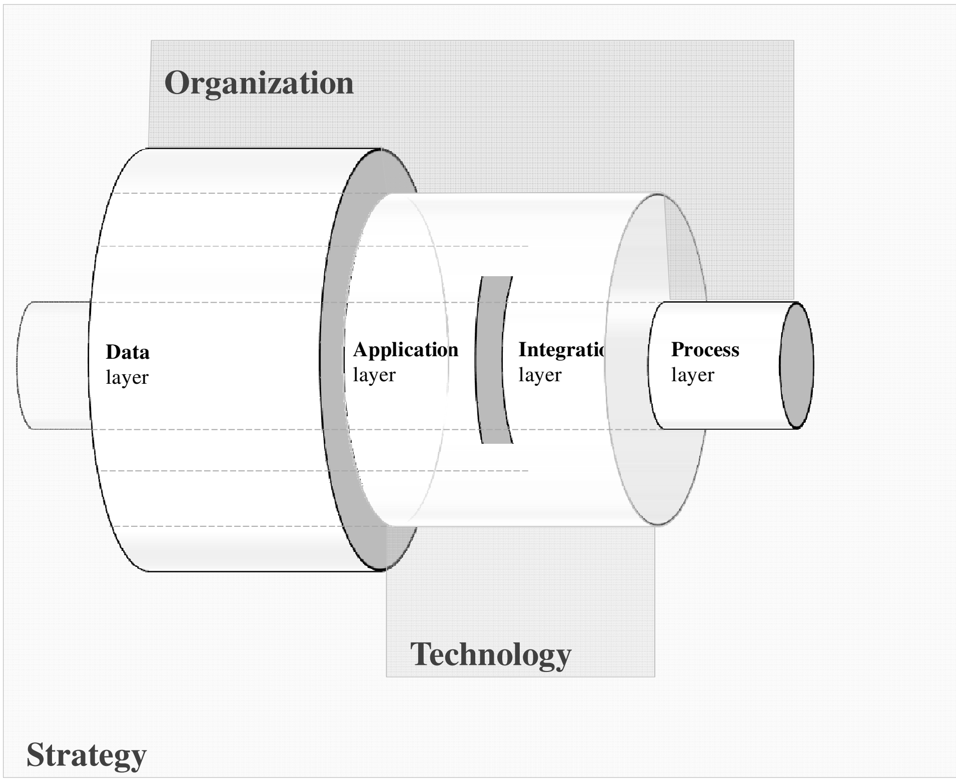

Figure 1 Layered representation of the conceptual framework

3 Processes assessment [Process layer]

A first analysis should focus on investigating the awareness and knowledge of business processes in order to obtain a first assessment of the internal processes maturity, as to support their evolution and redesign. In general, the idea of maturity is presented by sketching a number of growth stages that depict the potential-upward development or performance of organizations during several sequential periods of time [13].
Another important aspect to be investigated is how the firm is able to set up a process-oriented framework to manage the PLM corporate strategy implementation (see [12]), that is the (re)definition of the business process model according to the new PLM paradigm.

Thus, the first step aims to verify the formalization of internal processes, verifying whether all management procedure are shared among the Company. In this assessment area, formalization is an important aspect to be considered because is directly connected to the aim of redesigning the processes.

In this perspective, the analysis may proceed incrementally, inquiring at first the methods adopted to classify the processes, assessing whether business processes are properly described, clearly stated and shared among the company. Then, it is advisable to identify the processes elements and the modeling methodology to describe:

- processes logics;
- information and material flows;
- resources, responsibilities and roles in each activity.

The adoption of some process modeling standards (e.g. BPMN - Business Process Modeling Notation [14], IDEF - Integration DEFinition [15], etc.) or process reference models (e.g. CBM – Component Business Model) can effectively facilitate the universal understanding of the processes representation, which is necessary in order to allow cooperation in managing the product throughout its life cycle.

The second step, with reference to the process layer, is related to the analysis on how to lead the progress of business processes towards a PLM "to-be" scenario. To this extent, it is necessary to understand how the typical processes in PLM [12] match the company core processes in the company:

- Integrated product design and process specification;
- Dynamic requirement management;
- Integrated management of ideas, project and product portfolio;
- Service and maintenance data reuse at product development;
- Lifecycle environment impact analysis;
- Total lifecycle costing;
- End-to-end configuration control.

In this step it is either advisable to verify how product life cycle management perspective is widespread and entrenched in the organization. Indeed, the following contents [12] should be easily recognizable into the company's processes:

- Idea management;
- Requirements management;
- Product structuring;
- Product program planning;
- Change management;
- Project controlling;
- Risk management;
- Quality controlling.

Last but not least, as far as the processes scope is concerned, supply chain relationships must be investigated as well. PLM logic clearly cannot be adopted without an effective information sharing between customers and suppliers. Thus, it is necessary to verify which processes – on both customer and suppliers sides – require the exchange of product information in each stage of the product lifecycle. This will help to identify the specific intervention of process redesign (input and output material and informative flows, operating and time constraints, roles and resources, performance evaluation and measurement criteria) according to the new PLM point of view.

4 Integration assessment [Integration layer]

Once the business processes are explored, the analysis moves on the technological field. Indeed, an effective and efficient processes management is based on prompt and correct information management and on feedback collection along the entire workflow. To this extent, the organization needs the proper technological infrastructure to grant information sharing at enterprise and supply chain level.

One of the typical weakness of the traditional processes management view – where product lifecycle stages are seen as distinct and separate elements – may originate from the presence of "islands of information" associated with those few isolated functions where the acquired know-how stagnates [5][4][6]. Aiming to a truly cross-function product life cycle view, an information sharing system – capable to spread product data both internally and externally, to suppliers, partners and customers, thus eliminating these “islands of information” – is surely necessary.

On top of an high-level architecture software networking, an EAI (Enterprise Application Integration) may support the linkage of product data management and organizational processes implementing information sharing through the various enterprise systems [7][1][8]. EAI acts as a high-level agent that set the roles for the different integrated systems in the enterprise and , inevitably, its implementation calls into question the structure of application and data layers, which are discussed further on. We report the main critical aspects that an EAI has called to cope:

- EAI must answer to the need of system dependency, and affects the application flexibility;
- EAI implementation projects requires important technical comprehension;
- EAI must face different integration issues like information/data flows between business processes;
- EAI must be able to meet the daily requested performances and to assure exception handling and error-proof operations.

As seen for the process layer, the infrastructure assessment aims to understand the technological capability to support a PLM implementation project and to identify those aspects that need to be improved to fully switch to the PLM paradigm. On top of integrating the PLM system in some ERP system, it is important to focus on the elements which affect the decision to evolve/develop the technological infrastructure in order to enable a complete information sharing: among these, the specific requirements and operating constraints that characterize the interventions scope (such as the number of processes to connect, the amount and type of information to manage, the number of users to reach, the standards and security protocols to adopt, etc.) must be pointed out.

5 Applications assessment [Application layer]

This layer represents the technological connection point between the infrastructure and the product data collected from the processes. To this area belong all those heterogeneous – and often uncorrelated or independent – higher level applications dedicated to product information management and proper processes execution in the various functions, which need to keep a different point of view on the specific product. Their ability to interoperate ensuring a continuous data flow in alignment to the previously mentioned EAI aspects, plays a critical role in the PLM perspective [2][5][3][6] (e.g. despite the clear differences in the information systems, the CAD/CAE software used in the Design/Engineering division must however be promptly aligned with the application of the Maintenance, Logistics and Customer Service division to properly manage the preventive maintenance plans or spare parts replenishment).

Focusing on how to expand the awareness of integrating different applications – involving even suppliers and customers in the eventual choice of updating/purchasing new software – it is important to identify the operating requirements (in terms of capabilities, number of users, amount and type of data to manage, adopted standards, etc.) and constraints (related to capacity, security, budget, etc.). This predictable consideration should however be refined with the lessons learned from previous experiences of implementations of data interchange software in the company, on top of the analysis of the compliance of the selected applications with other systems (other applications or infrastructures), both inside the organization and outside it.

Information must be collected in order to point out how each of the company's functions can support the previously identified PLM typical processes: a gap analysis in order to identify the requirement and specifications to be met can thus be performed.

6 Product data assessment [Data layer]

The base layer in our framework is represented by product data. This is not intended as a mere file archive, but as a more complex data structure containing all information and metadata needed along the entire product lifecycle [1].

At first, the number and typology of products and parts managed in the company need to be analyzed in order to understand the complexity of the scenario. This may seem a simple task but, in the greatest part of the cases, companies archive data in unstructured or inappropriate databases or, eventually, on paper. Thus, the complexity of this phase should not be underestimated. Data should be classified in accordance to the stage of the product life cycle [12]:

- design data;
- engineering data;
- maintenance data;
- configuration data;
- assembly data;
- production control data;
- data for activities scheduling on the product.

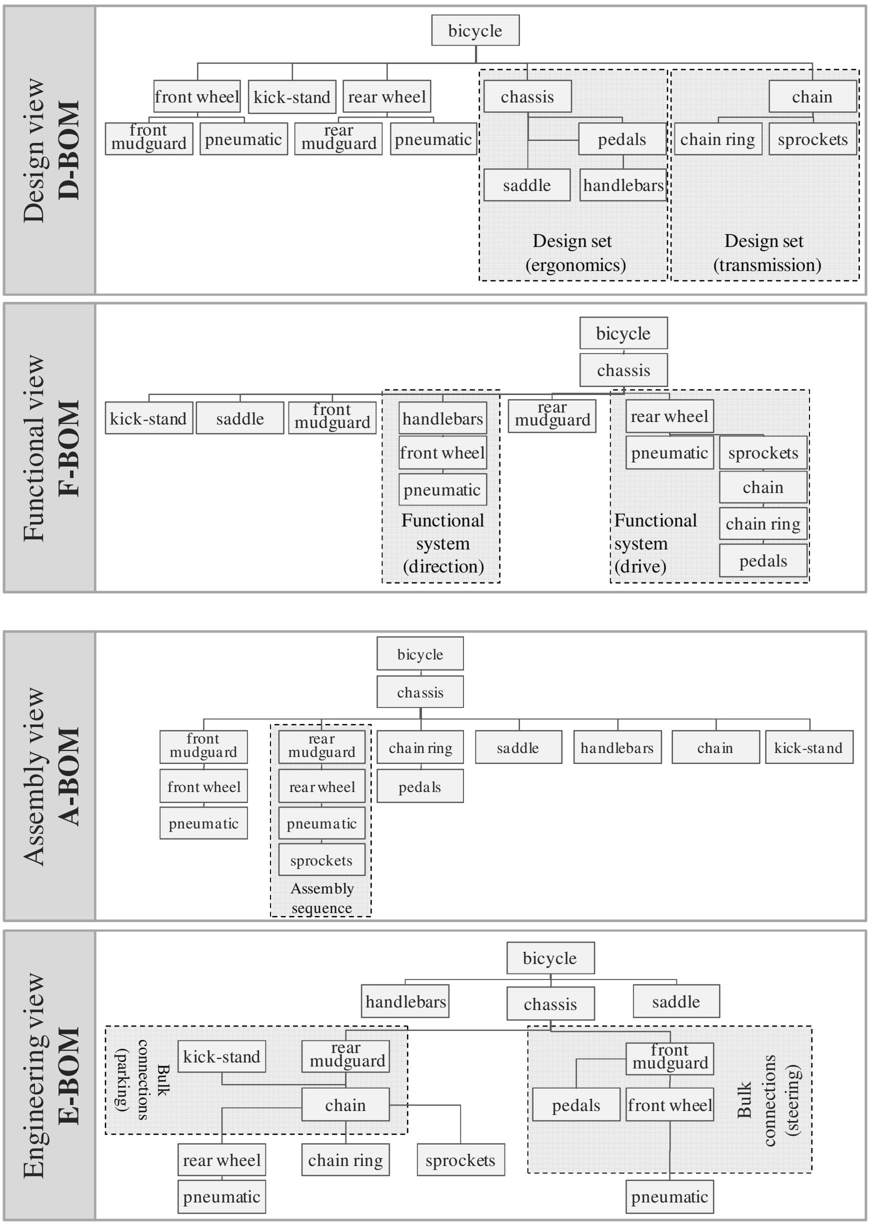

Figure 2 an example of product data break down structures according to different points of view (X-BOM), related to a bicycle bills-of-materials.

At first, it is important to point out *which* product data should be taken into account at each stage of its life cycle and, therefore, how the product configurations are managed and shared in order to properly arrange the required information. In this regard, suitable product break down criteria must be defined to identify the elementary units and what information should be collected. Product information can be structured in different ways: a functional point of view (F-BOM) will clearly differ from an assembly point of view (A-BOM), which in turn diverge from the structure used in the engineering division (E-BOM), etc. as show in figure 2.

The adoption of a unique protocol for PDM (product data management) allows to eliminate the conversion operations required to share information among different information systems. An ideal solution would be a default standard for product data management which can ensure full interoperability between software applications across the entire infrastructure. For this purpose, the knowledge on information structuring standards should be assessed both in the company and among the partners. In example, PLM requirements may be effectively supported by the STEP Application Protocol 239, namely the ISO 10303-239 standard, also known as the PLCS (Product Life Cycle Support) [9][6][10][11]. At last, it is important consider the characteristics of the application used to create, edit, review and share the product information.

7 Conclusions

A conceptual framework that can support a large company, or a group of companies, in defining the assessment principles on which a PLM implementation project should be based on has been presented. The assessment model is required in the starting phase of the PLM project in order to understand the current scenario – inside a specific company or among several companies, at a corporate level – and the element that must be improved to support the transition from a traditional to a product-oriented approach. This may effectively help in identifying which specific interventions may be needed on top of creating a higher level of concern on the topic, together with the commitment that encourages the creation of a positive climate on which any kind of cooperative project should be based on.

Table 1 Analysis scheme for the data layer

	Internal context analysis	**Toward the PLM approach**
Process layer	• Processes identification and classification; • Standard modelling approach for processes representation and analysis; • Processes performance measurement;	• Level of knowledge of PLM concepts; • Evaluation of processes in PLM areas; • Identification of linkages between internal and external (suppliers/customs) processes; • Identification of the necessary connections to implement the PLM logics.
Integration/Application layer	• Scenario analysis (requirements, operating constraints, etc.); • Adopted infrastructure/application and lessons learned from previous experiences (limits, constraints, etc.). • Analysis of the process coverage through infrastructure/applications;	• Identification of PLM areas to be serviced through infrastructure/application; • Infrastructure capability to interact with external (suppliers/customers) systems. • Compliance with other internal and external (suppliers/customers) applications and infrastructure.
Data layer	• Product data set complexity; • Managed product data informations; • Typology of product data (format).	• Management and sharing of product data break down structure; • Standards for the interoperability with partners.

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Chapter 10
PLM Education

PLM master curriculum design at University of Novi Sad - Faculty of Technical Sciences

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Abstract: Product life cycle management as a relatively new, integrating engineering discipline, attracts attention of both industry and academia. An Industrial engineering master course has been developed at University of Novi Sad, Faculty of Technical Sciences in a scope of TEMPUS IV project entitled „Master studies and continuing education network for Product Lifecycle Management with Sustainable Production“. This paper presents the development of curricula from the initial idea and the context in which it was conceived, through the premises on which the curriculum is developed, and the structure of subjects and other teaching elements in it, as well as the first results of implementation.

Keywords: Product lifecycle management, curriculum structure, skill, attitudes

1 Introduction

Although the product lifecycle concept has represented a central element of manufacturing and marketing theory since its development in the 1950s, it recently has begun to attract attention in both industry and academia, mostly due to its broad scope and possibilities of collaborative design [1].

Many companies in the world have already recognized the importance of investing in the implementation of this concept in their business. In order to carry out this complex implementation successfully, it is essential that there exists experts in this field.

The Faculty of Technical Sciences in Novi Sad, a few years ago, noted the need for educated professionals in the field of PLM at the master level. This was the reason for joining to the initiative for new Tempus project "Master studies and continuing education network for Product Lifecycle Management with Sustainable Production", MAS-PLM (2009-2012).

As part of the TEMPUS project, four faculties from the Western Balkans cooperate. Besides the Faculty of Technical Sciences, Novi Sad, Serbia, in this project are involved Mechanical Faculty, University of St. Kiril and Metodij, Skopje, Macedonia; Faculty of Mechanical and Electrical Engineering and Naval Architecture, University of Split, Croatia and Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia.

For the leading foreign partners is selected Politecnico di Torino, Turin, Italy. Politecnico di Torino has many years of experience in PLM, which was acquired in cooperation with companies from the region, primarily with Fiat, with whom they established a special cooperation in this field. In addition, the Politecnico has accredited Master in PLM one-year study program that served as a model for the development of curriculum.

Project is supported significantly from Siemens, a company that is one of the few in the world that developed comprehensive PLM software and is still improving it. Siemens has already successfully implemented this software with users such, as among others, Fiat, Heidelberger Druckmaschinen AG, Ford Motor Company, Procter & Gamble, Volkswagen, Xerox Corporation, etc. In the first place, Siemens are contributing to this Tempus program with their software:

- Teamcenter for Digital Lifecycle Management,
- NX for Digital Product Development,
- Solid Edge,
- Technomatix for Digital Manufacturing,
- Femap with NX Nastran and
- Velocity Series PLM, provided for small and medium sized businesses.

The main objectives of the TEMPUS project are:

- The four faculties have a duty to develop, based on the common premises, the original PLM curricula for education at Master level.
- Supporting the implementation of the curriculum in the first two years.

This support takes place at several levels:

- Obtaining PLM laboratory equipment,
- Training teachers,
- Development of teaching materials,
- Financial support for training the first two generations of students and
- Professional teaching staff travel, in order to exchange experiences with colleagues from other universities, as well as from the Politecnico di Torino.

University of Novi Sad, Faculty of Technical Sciences (UNS-FTN) has created, for the purposes of this master program, a brand new laboratory (Figure 1) and that is equipped with standard classroom equipment and the laboratory equipment with ten desktop computers, two servers, video beam, and two mobile workstations and Siemens PLM Software.

2 Curriculum: design philosophy, target groups and teachers stuff

In education climate of 21st century, the expectation is that all students will make adequate progress so, it is critical to align curriculum objectives with teaching, and assessment more closely than before [2]. Having that in mind, the structure of curriculum illustrated in Figure 2 is a representation of six fundamental questions, which were guidelines in a creation of the curriculum:

1. Which are the external constraints (labor market needs, length of training, funding, etc.)?
2. Who will be the students (target groups)?

3. What should be taught (goals and objectives)?
4. How should it be taught (equipment, literature, activities and experiences)?
5. What is the teaching staff necessary to implement such a curriculum?
6. How should learning be measured (tests and assessments)?

Figure 1 New PLM laboratory at UNS-FTS

Figure 1 New PLM laboratory at UNS-FTS

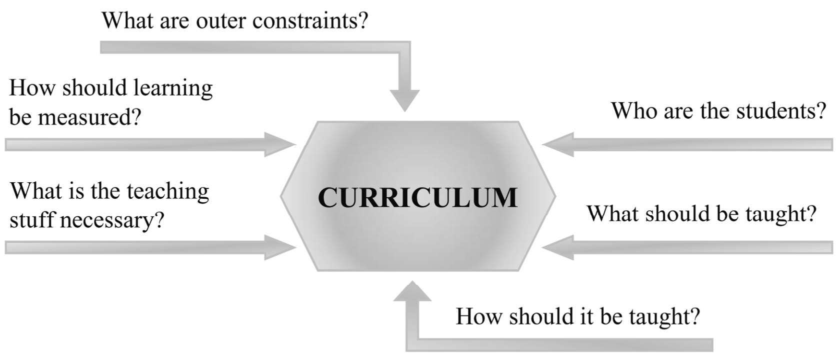

Figure 2 Influences on curriculum design

The intention of the creators of the MAS-PLM curriculum is to promote a new type of expert who will have complex technical competence. These competencies include all the necessary theoretical knowledge and practical skills, engineering, but also managerial, as well as the attitudes, the foundation of which is, in this curriculum, placed special emphasis. That kind of expert should have the ability for research, as well as specific skills in product development and management in all phases of its lifecycle. They should be prepared to apply the learned methods for process management in different areas, such as production, services, public activities, and all of this should be supported by the latest information technologies. Furthermore, students must, during their education, to develop attitudes toward their work and work in the PLM environment, which will ensure their adaptability, further development and quality response to the challenges that, such a demanding access, will put in front of them.

This curriculum covers education regarding functional requirements management, production processes, production planning, resources planning, production automation, maintenance, service, and recycling. The main goal is to reduce production time, failures, and production costs, and, at the same time, increase product quality in all phases of the product lifecycle. A successful MSc graduate in PLM has to be able to [3]:

- Show mastery and critical thinking of the PLM knowledge and skills and professional issues necessary to begin practice/research in System Engineering (SE).
- Work as individual or as part of a team to develop and deliver high quality engineering and management of all phases during the product lifecycle, being able to analyze its level of quality.
- Identify, analyze, and reconcile conflicting project objectives, finding acceptable compromises within limitations of cost, time, knowledge, existing systems, and organizations.
- Analyze, design and document appropriate solutions in more than one application domain using PLM approaches that integrate engineering, social, legal and economic concerns.
- Demonstrate understanding of current theories and describe critical analysis and application of models and techniques that provide a basis for the problem identification and analysis, process design, development, implementation, verification, and documentation.
- Demonstrate an appreciation and understanding of the importance of negotiation, effective work habits, leadership, and good communication with stakeholders in a typical PLM environment.
- Learn new theories, models, techniques, and technologies as they emerge and appreciate the necessity of such continuing professional development.
- To understand the importance of sustainable production and energy efficiency and their principles and to build them into every project in whose creation is involved in.
- To understand the necessity of disseminating knowledge, skills and attitudes acquired during the education in this master program, and to exert it in their work environment.
- To implement quality and continuous self-evaluation in their work environment.

Target groups for MAS-PLM studies are:

- Current full-time working engineers with relevant experience and BSc,
- Fresh graduates of Engineering, Management or Informatics with BSc diploma,
- Mature engineers or researchers, which require retraining or undertake career development and
- Students wishing to embark on a research programme, at a PhD level, in Industrial Engineering and Management.

The implementation of the curriculum in direct work with students involves 12 professors and 10 assistants whose expertise covers a large part of the field of PLM. It is planned a lecturing of visiting professors from the University of Turin, Skopje, Zagreb and Split, that would deliver lectures in certain modules. However, given the fact that the

PLM is the completely new area in the educational system in Serbia, it is necessary to ensure the professional development of teachers in the field using PLM software. Experts from Siemens's companies held, in the newly formed PLM laboratory at the Faculty of Engineering, two cycles of professional development: two-day administrator training in installing and maintaining software, which is 16 hours of training; and twice five-day professors training to use Teamcenter software, which is about 80 hours of training.

However, in order to educate high-quality masters of this profile it was required to take additional efforts.

For the realization of PLM curriculum, as a teaching stuff are selected professors and assistants who have significant experience of cooperation with industry in Serbia and the region and who have worked on the implementation of modern approaches to management and production systems at various levels.

The team that created the curriculum has analyzed its implementation from the aspect of the best way to exert its highest quality, especially regarding students who are to acquire practical skills and to develop attitudes. Furthermore, the arguments for the implementation of the curriculum orientation to process - based learning and to project - based learning were considered [4]. Although there were quality arguments for both approaches, the team concluded that, given the nature of the PLM approach, the combination of both is required so they are supposed to play complementary roles. The key reasons for this approach are:

- PLM approach is, in itself, a process (either circular or open) [5],
- In order to pass each of the stages of the process and to adopt a holistic approach to PLM, it is necessary for every student to be part of the project, which involves simulating all phases of the PLM process in a concrete real product.

In order to prepare teachers for successful implementation of the curriculum, especially from the aspect of the selected combined approach, it was necessary to organize their planned professional development on those principles. Studying international experiences of universities that successfully implemented education in PLM [6] using an Industry-Sponsored Project, the authors have recognized the necessity of curriculum's close collaboration with industry. The result has been initiated and cooperated with the company for the production of transformers - ABS Holding, Belgrade, Serbia. This company has, through a series of contacts with team members, recognized the need to organize their business, in the future, on the principles of PLM. In order to go in advance to these changes, the company accepted the cooperation with UNS-FTN. Therefore, the central part of teacher training for using PLM software was conducted on the example of the transformer, whose complete electronic documentation is provided by the manufacturer - ABS Holding. Thus, initiated cooperation offers many possibilities for further joint action in areas of professional development of students. These and other aspects of cooperation with the powerful and advanced companies, represent the general orientation of the team and the entire teaching staff directing PLM curriculum.

3 Structure of PLM curriculum

Numerous are the efforts of the experts to define the PLM [7] and, more precisely, to formulate the phase of the new strategic approach to manage the product information efficiently over the whole product lifecycle. In these efforts, they went from phases being too big and general, to the excessive number of phases of very small stage. The scope of PLM is not well defined, and concepts have not yet been firmly established in either academia or industry. One of the high quality, comprehensive, and at the same time not too complicated attempts to define the area of management longevity of the product is given in [1] the two-dimensional cross-section of Role-based and functional perspectives. The biggest challenge for the team that created the curriculum was to identify the matrix covering the complex subject of PLM, which is supposed to fit into the framework of one-year master course.

All seven subjects (compulsory and elective) are placed in the first semester. Lectures are divided into compulsory core subjects and elective subjects [3]. There are five compulsory subjects and two elective subjects (Table 1).

Table 1 List of subjects of PLM master studies

No.	SUBJECT TITLE	ECTS
	1. Semester	
	Compulsory subjects	
1	PLM platform	5
2	Product development and management in PLM	5
3	Information systems for PLM	5
4	Sustainable production and LCA	4
5	Professional internship	3
6	***Elective subject 1***	
	Management of PLM projects	4
	Technologies for disposal at the products' end-of-life	4
	Innovation and change management *	5
	Designing for specific environmental conditions *	4
7	***Elective subject 2***	
	Systems and devices for product tracking through life cycle	4
	Product service and maintenance	4
	Product data management	4
	Intelligent production and effective management *	5
	2. Semester	
8	Research work as a basis of Master thesis	15
9	Master thesis	15
ECTS total:		**60**

* subjects which are an integral part of the curriculum for the Master of Engineering Management

Each of the two electives, students have the opportunity to choose among four offered and thus guide their further professional development. According to accreditation rules in Serbia, students have to do a practical training in a suitable company or institution. The aim of this internship is to apply knowledge in practice and acquire practical experience in real time conditions. Therefore, students of PLM have to do a professional internship. It is expected to be done also in the first semester. The second semester is dedicated to the student's research work and writing of their master thesis based on consultations and instructions given by the student's thesis supervisor [8].

Besides Industrial Engineers, the Faculty of Technical Sciences has also been educating, for the last 12 years, the Bachelors and Masters of Engineering Management. Bearing in mind the fact that the field of PLM is significantly associated with Engineering Management, in the curriculum is given the choice of three elective subjects that are an integral part of the curriculum for the Master of Engineering Management. All other subjects were created purposely for this curriculum. The value of the PLM master studies is 60 ECTS credits. The studies are organized in two semesters. One academic year consists of two semesters and lasts for 30 weeks (1 semester = 15 weeks). The first semester consists of lectures, while the second semester is devoted to the final work / thesis.

Namely, the PLM is a wider concept and this curriculum cannot encompass all the areas of PLM, but we have covered, in our opinion, most significant ones (Figure 3).

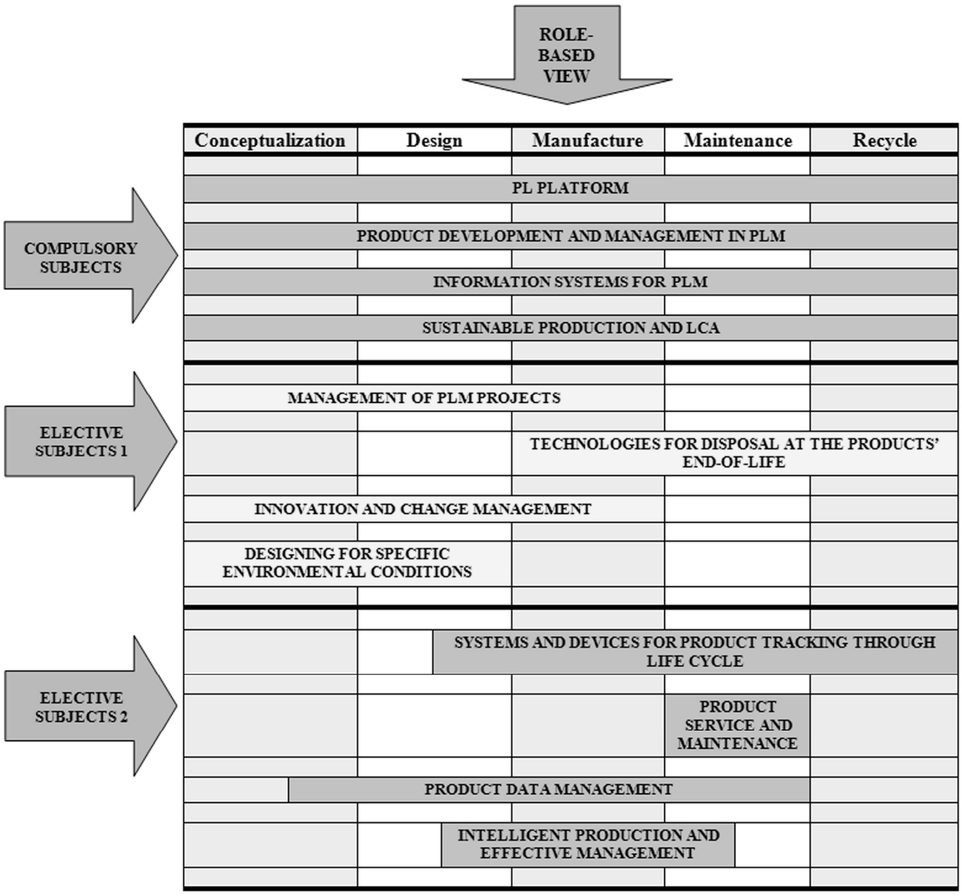

Figure 3 Areas of PLM that are covered by the subjects of the curriculum

Having in mind the target groups, from which students are expecting to come, to this master program, they should be carrying with them the knowledge of product design from areas where they worked on from the bachelor studies or professional experience, if they are employed. In this master program, they should extend their earlier acquired knowledge and skills by adopting, at the level of proactive application, the PLM vision and ability to implement it in future professional practice. Conclusions based on this are:

1. Compulsory subjects cover almost the entire field of PLM, as they are designed in a way that each subject from its aspect enlightens the approach. Associated together, for the students, they form a general picture and a holistic view of the area of PLM.
2. Elective subjects are covering only the certain parts of the PLM field and are aimed for students to improve and deepen their knowledge, skills and attitudes, moving in the direction of their future research work and master dissertation.
3. By choice of two elective subjects, a student has the opportunity to make a combination of PLM fields in which he/she wants to evolve.
4. The table doesn't show the compulsory subject "Professional Internship" because its area on the PLM project will depend on the company in which students provide their own training, as well as on the domains which he is enabled to access.

Study program complies with European standards in terms of conditions of entry, duration of study, graduation and modes of study [8]. Programme is accredited in February 2010 and since February 2011 has begun its implementation.

4 First results of curriculum implementation

The terms of admission to this study program allowed the other engineering profiles as well as managers and IT graduates, so a great interest was shown for entering to this study program. For projected 32 appointments, 65 candidates enrolled. After the entrance exam, a following structure of enrolled students is obtained (Table 2).

Table 2 The structure of enroled students by field and degree

No. of students by field and degree			Total	(%)
Architecture	BSc	/	1	3,13
	MSc	1		
Electrical engineering	BSc	5	6	18,75
	MSc	1		
Environmental engineering	BSc	/	1	3,13
	MSc	1		
Graphical engineering	BSc	1	1	3,13
	MSc	/		
Industrial engineering	BSc	1	5	15,63
	MSc	4		
Engineering management	BSc	7	13	40,63
	MSc	6		
IT	BSc	1	1	3,13
	MSc	/		
Management	BSc	1	1	3,13
	MSc	/		
Mechatronics	BSc	/	1	3,13
	MSc	1		
Technology	BSc	/	2	2,65
	MSc	2		

The most significant participation of enrolled student is coming from the area of Engineering management. It could be explained from the one hand with the great level of coherency between Engineering management and Industrial engineering, and from the other hand with a strong school of Industrial engineering and management with the great number of graduates. It was surprising that on the second place of number of enrolled students are Electrical engineering graduates. This is very encouraging fact because Electrical engineering is considered as very difficult and the best students are enrolling in this area. One of the reasons for this could be that they feel that their knowledge from computer science, control and drive technologies could be usefully applied in this new area. As could be seen from the table 2, five out of six students from this area, want to continue their education, after graduating at the bachelor level, to the master level in PLM. Another interesting fact is that one master in architecture enrolled for PLM master. This could be the sign that the broader context of PLM could be applied in the area of building object and urban planning. Gender structure is completely equal (16-16). The same is applicable to the number of bachelor and master graduates. Only three of the enrolled students are employed at the moment. Looking at the age of enrolled students (Table 3) it could be noticed that the most of them (10) are from generation 1987, who are the good student that never lost a year during their studies.

Table 3 The structure of students by their ages

Age	Number
younger	1
1987	10
1986	4
1985	8
1984	4
older	5

5 Conclusion

PLM represents a powerful approach to improve the company's strategic and operational excellence. In order to make possible such a step forward for the companies, it is necessary to form properly educated professionals. They should possess the theoretical knowledge necessary to provide companies with the new, modern way of thinking and approach to business, which compiles with the PLM vision, as well as to provide them with practical skills in implementing such a vision.

The way the steps are defined in the algorithm to create the curriculum (Figure 1) allows a quick and reliable evaluation and revision of curriculum, with the purpose of its adapting to future developments in the labor market and the needs of the economy of Serbia and the region. One of the most important premises of creating a curriculum in higher education is to provide a flexible curriculum, especially if the field that curriculum is covering is multidisciplinary, modern and very fast growing and changing, as is the case with the PLM. During the development of PLM curriculum, following companies express their interest for the masters in this area: FIAT, Ball Packaging Belgrade, US Steel, Gorenje, etc. As it could be seen, those are the subsidiaries of multinational companies, so this curriculum could be generally useful in other countries. Following the example of multinational companies and their practice, the surrounding companies in the region could start with applying PLM concept in their operations.

In the future, it would be good to keep the lines of the following:

1. Monitoring the implementation of curriculum and correction based on results of the first two years of the program, the experiences of teachers and students, especially those who graduate in the shortest time, business and production needs in Serbia and the region.
2. Continuous professional development of teachers, enabling more frequent contact with professionals who implement PLM curricula at quality colleges around the world, and improvement in teaching methods, because the education of students in such a demanding and modern curricula is a special challenge.
   a) Finding the companies from the environment that would be willing to cooperate with the UNS-FTS, as follows: in the first stage to give permission to make the experiment with them and to implement the PLM concept, in the second stage, if they are satisfied with the results of the experiment, to adopt PLM concept and implement it in their work, to ensure that students of this master program monitor the implementation process and gain experience.

Obviously, the Faculty of Technical Sciences in this master program is going to meet future developments in the Serbian market (and market of the Western Balkans and Southeast Europe) and in the European integration of Serbia. This integration, inevitably imply a substantial modernization of existing production processes in domestic companies, but also modernization of the process's organization and monitoring the life of each product in order to ensure repetitiveness of the quality, as well as the rapid correction of products in response to market requirements and traceability throughout its life span. Graduate masters will be competent to assume this important role in the economy of the region.

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