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Through-Life Integration Using PLM

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Abstract

It is widely agreed that organisations would benefit from a PLM implementation founded on a standard structure that integrates through-life information and knowledge. Thus, this paper describes a PLM data structure that provides a standard repository of data through all the stages of the lifecycle: conception, manufacture, and operation. This structure classifies the data into project, product, process and resource, and has been implemented into the PDM system Teamcenter Engineering as part of a case study with a vacuum pump manufacturer. A methodology to implement a knowledge structure from an ontology editor into PDM system is also presented.

Keywords:

Product Lifecycle Management, PLM, data structure, design, manufacturing, service, knowledge

1. INTRODUCTION

In today's global and competitive market, companies are facing many challenges namely shortening of the time to market, changing regulations, price competition, increasing product complexity and diversity, innovation, support and maintenance of the products, environmental concerns and end of life issues, and many others. Product Lifecycle Management (PLM) systems can support these challenges by improving the accessibility and trustworthiness of intellectual assets, and by managing resources and processes across the whole product lifecycle. In fact, PLM provides a collaborative environment to create, manage, share and use all product related data, since it eliminates the technology silos which have previously limited the interchange of information across the product lifecycle.

Thus, organisations are implementing PLM systems to achieve business objectives. However, in order to achieve these objectives, it becomes crucial to define a suitable data structure. Across the product life cycle, product, process and resource related data must be created, stored and managed (i.e. CAD files, product specifications, customer requirements, NC codes, cost analysis, project plans, service processes, etc). Though these intellectual assets do not originate in a standardised format, they must be stored in a common data structure.

Today's organisations possess vast amounts of knowledge widely spread across different sources, and it continues increasing exponentially. This knowledge, which can be described as an intangible asset of the company, resides everywhere, varying from emails and instant messages to detailed reports and PowerPoint presentations. Companies are also aware of the critical importance of maintaining this expertise and intellectual property for process improvement and product innovation. Therefore, in the current distributed organisational environment, having a data structure which integrates product knowledge as a strategic asset, would drive future business success.

This paper combines two relevant topics related to PLM: product data structuring and knowledge management in PLM. Various sources can be found related to each of the concepts, but there is little combining both.

In the next section of this paper an overview of recent research on data structuring and knowledge integration within PLM is presented and discussed. In section 3, the current PLM environment of a vacuum manufacturer is presented. The data structure developed in this paper is presented in section 4. In section 5, the tools used in the execution of the research – Protégé and Teamcenter Engineering – are compared. Section 6 describes the methodology to integrate the knowledge from the knowledge editor (Protégé) into the PLM system (Teamcenter Engineering). In section 7, various scenarios implemented in PLM, which simulate real business cases, are presented. Finally the last section summarises and concludes the research.

2. LITERATURE REVIEW

Today's organisations are looking to PLM as the strategy to achieve product excellence and business objectives. However, in order to achieve these objectives, it becomes critical to define a product structure since it is the core of the PLM implementation. Schuh et al [1] state that the data structure describes the structured relationship between product's components, and integrates all the data and documents related to the product (e.g CAD files, NC codes, product specifications).

In this context, organisations would benefit from a standard data structure. Nevertheless, according to [1], recent researches and evidences from the practice have revealed that a unique reference model cannot define a standard product structure, since processes and products vary from one company to another. Moreover, as stated in

[2], there is still a lack of standard representation of data which identifies and details complete and corporation-wide integrated product information architecture.

Zina et al [3] also agree that implementing a generic reference model is ineffective, so the implementation has to be adapted to the necessities of the particular situation. Thus, they propose a methodology to particularise a reference model. This methodology starts with the selection of a reference model applicable to the sector of industry related. Then this reference model is converted in a generic model by studying several case studies of the implementation of the selected reference model. And finally the generic model is particularised to the specific situation in order to achieve the required model.

Based on the fact that a unique reference model cannot be applied to model the product structure of every company in the industry, [1] presents a methodology for product structuring and a set of six customised product structuring reference models to address the specific needs of each existing project type.

Sudarsan et al [2] propose a product information-modelling framework which is intended to address this issue, supporting the full range of PLM information needs. The framework consists of four major components that form its kernel: the NIST Core Product Model (CPM) and its extensions, the Open Assembly Model (OAM), the Design-Analysis Integration model (DAIM) and the Product Family Evolution Model (PFEM). The main objective of implementing the information modelling framework is to provide a standard repository of the full product information at every phase of the design process, *"serving all product description information to the PLM system and its subsidiary systems using a single, uniform information exchange protocol"* [2]. However, the framework described cannot be implemented in a PLM system because: (1) the framework is a first version of a product modelling architecture as it does not model and include every product information component. (2) Possible information interchange problems due to the heterogeneous nature of the framework. And (3) full PLM system products needs and product information needs have to be identified to develop a complete conceptual framework.

On the other hand, [4] describes an integrated data model and implementation approach for a PDM system based on the STEP (Standard for the Exchange of Product) standard, the PDM schema. The PDM data schema proposed, which includes product structure management, configuration management, document management, workflow management, effectivity management and engineering change management; is a standardised product data architecture that fulfils the PDM functionalities.

A study described in [5] presents a knowledge management framework to support consumer-focused product design; the authors state that it is crucial that the knowledge of a company integrates its product, process and resource elements. Thus, they describe the product-process-resource model (PPR). In this model, the product configuration is represented by the following relationship: *"configuring the product (product structure, materials bill) → configuring the business process (process structure, operation types) → configuring the resource (structure of system, equipment and staff types)"* [5].

Huang and Mak [6] also express the importance of integrating product, process (activities) and resource components in the design collaborative environment and describe the product realisation process as *"a triple P, A, R.of Products which compete in the market, Activities which realise products, and Resources which are available for realisation. P, A, and R are interrelated to each other. Interactions can be explained that products consume activities and activities consume resources"* [6].

Other research studies present other methods of modelling product related information such as the product-process-organisation (PPO) model. But according to [7], the relationship between the three core concepts and other information objects as well as the relationships between them are not comprehensible.

In this context, Han and Do [7] propose a top-down object oriented model named 4P2C model. The 4P2C stands for product, process, project, participant, cost and collaboration. Based on this, they describe six submodels that compose a full CPDM model.

On the other hand, although Kim et al [8] agree that the PPR model contributes to address all the engineering information related to the product, they argue that human related information, which is frequently considered as a part of the resource information, is not managed properly in PLM systems. For this reason they propose a PPR+H model, which is an XML-based schema that integrates and manages information about product, process, resource and human in PLM.

Eynard et al [9] describe a PDM system named VPM-Chains, based on Enovia, providing a detailed class diagram of the product structure and the workflow management. The proposed system integrates the product with the process and the resources based on a framework for collaborative work, which includes three applications: (1) a Web portal to support access to product data, (2) BuildTime application for modelling processes and (3) RunTime application as a workflow engine for running the processes. At the last instance an element called briefcase provides the integration of product, process and resources. This briefcase contains elements of the process, product data and metadata.

Regarding to the role of PLM in knowledge management, current enterprises possess vast amounts of knowledge widely spread across different sources, and it continues increasing exponentially. This knowledge, which can be described as an intangible asset of the company, resides everywhere from emails and instant messages to detailed reports and PowerPoint presentations. Companies have realised of the crucial importance of maintaining this expertise and intellectual property for process improvement and product innovation. In fact, in the current organisational distributed environment, knowledge is a strategic important asset which drives future success and must therefore be correctly controlled.

Knowledge Management (KM) is defined as *"the process that deals with systematically eliciting, structuring and facilitating the efficient retrieval and effective use of knowledge. It involves tacit knowledge of experts and explicit knowledge, codified in procedures, process and tools."* [10]

Sharing and controlling knowledge has become a challenge to organisations due to the complexity of the relationships within a company and the difficulty to capture, share and make use of the knowledge. Recently some IT solutions like ERP, PLM, CRM and SCM have begun to support and facilitate knowledge sharing, but there is still a clear need for more effective frameworks related to this issue.

PLM supports the integration of the different variety of knowledge along the entire life cycle, allowing users work more effectively. In fact, having a standard knowledge management embedded into PLM improves the efficiency (i.e. reduces the learning curves), allows process excellence and encourages innovation.

Ebert and Man [10] present a knowledge-centric PLM system that has allowed Alcatel-Lucent to achieve effective interaction of engineering tools, processes and people. This approach that combines KM and PLM brings together knowledge about products, processes and projects. The implementation of the system has brought a reduction in cycle times, an improved communication, a reduction in rework and overheads and more benefits.

Other sources such as [11] propose a mechanism of integration of a PDM system and an expert system – a type of KM system – through a Java based program. This program, which also includes the knowledge management system Protégé 2000 created by Stanford University, can be distributed as an applet to the PDM system (in this study Windchill PTC) enabling CLIP rules to be added to the knowledge base. It also allows a very intuitive and graphical user interface based control underlying ontology of the knowledge base, and a new functionality which consists in including the process of entering knowledge in the knowledge base into the workflow.

In contrast, Cheung et al [12] describe a methodology for structuring knowledge and integrating it in product development. This methodology employs a knowledge management editor – Protégé - that uses an ontology to capture, organise and represent knowledge. Then, the knowledge is converted into XML files so that it can be stored in a web-centric PDM system to support a distributed and collaborative product development environment.

In summary, the literature has revealed that a standard data structure that includes information and knowledge related to the product through the entire lifecycle does not exist. It also suggests that such a structure would facilitate the implementation and customisation of the PLM system in today's organisations, improving data and information sharing within and between enterprises.

The product-process-resource model described has shown its benefits to integrate all life cycle data. The problem with these PPR models is that there is not a top level view which integrates the three components.

3. AS-IS MODEL

The AS-IS model, which represents a picture of the current PLM environment of the vacuum pump manufacturer, has revealed that the PLM system implementation is not mature. Dassaults SmarTeam is the PDM system implemented, however it is only used to manage and control CAD files created by Dassaults Catia V5 – the main CAD software used in the company. In fact, the organisation is not taking advantage of the implementation of any workflow, such as the design release process or change management; or any other feature such as BOM management, or drawing number management. Thus, these activities are carried out by other systems such as Microsoft Excel and Access; by web based tools or by paper work, as shown in Figure 1.

For instance, it has been highlighted by the vacuum pump manufacturer's employees that there is still plenty of paper work in tasks such as release process, which slows down the development of the product and could be improved by implementing them into the PDM system. In addition, there is also a lack of integration among the different systems implemented. This is the case of the PDM system, which is not integrated with MAPICS, the main ERP system used in the company for manufacturing operations. This issue entails manual data entering (i.e. the BOM has to be manually entered into MAPICS), which requires a large amount of resources. Although all the

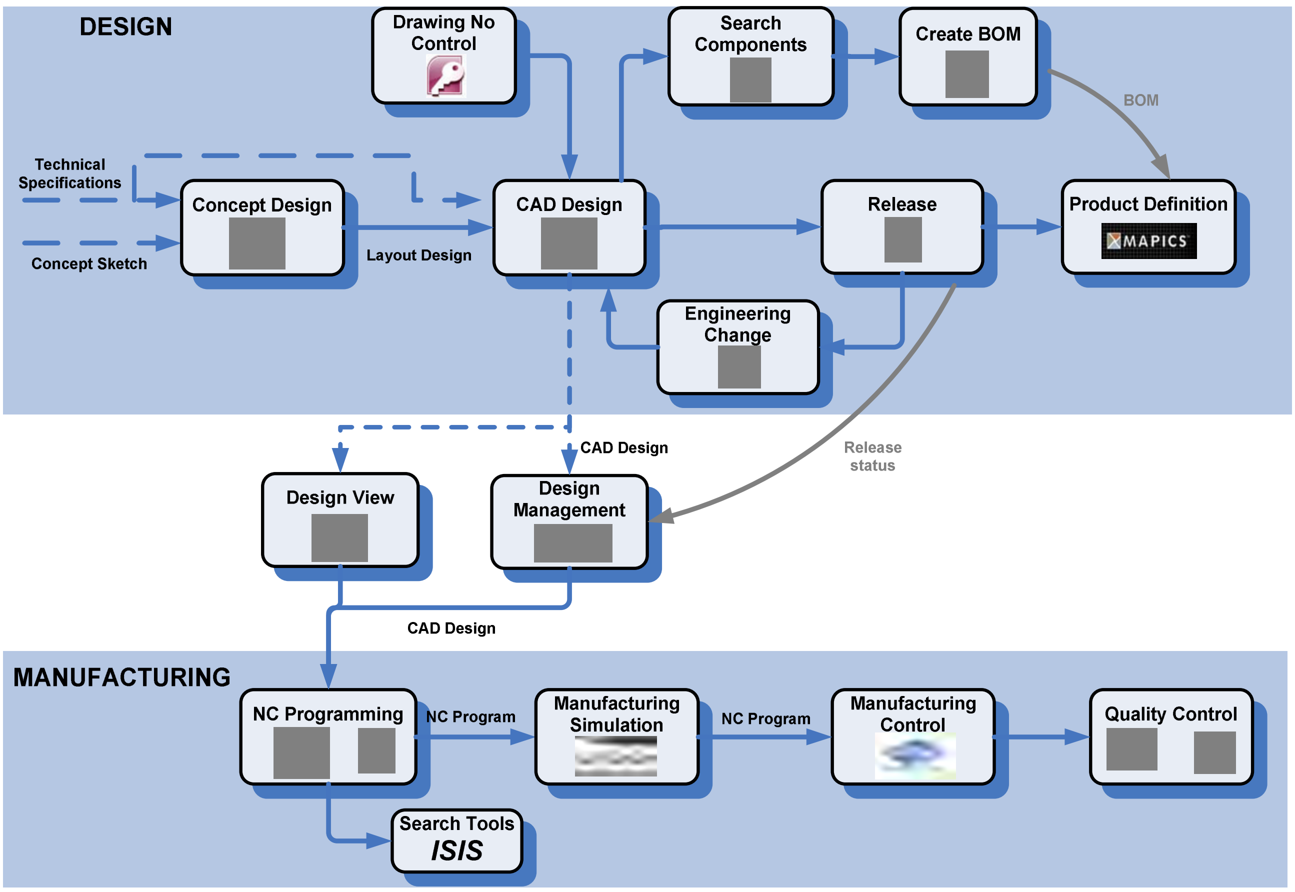

Figure 1. AS-IS model of a vacuum manufacturer

sites use SmarTeam PDM system and MAPICS, there are no standard procedures for all the sites and each site maintains its own processes and systems. For instance some sites use various CAD systems or even a different PDM system.

Then, where does the organisation store all the product related information? The answer is in the 'Project Folder'. Every project has its own project folder where all the relevant data (CAD files, requirements, FEA analysis results, manufacturing data and files, marketing information, service information, project planning, etc) is stored. This folder is also used to share and transfer all kind of documents and designs between engineers. However, files are often stored in personal computers and transferred by ftp, CD or other memory storage devices, or email. This practice entails that there is very little support for sharing, version control and release.

The problem of this project folder is that it does not offer the functionalities a PDM system does, such as product structuring, workflow editor, revision control and many others. For this reason, it will be beneficial for the organisation to have a data structure implemented in PLM that replaces the project folder. This implementation should be based on a data structure that integrates all product related information.

4. PLM DATA MODEL

The data structure integrates all data and documents (e.g. CAD models, requirement documents, BOM, NC codes, etc) through all the stages of the lifecycle. According to [2] there is a lack of standard product information architecture. The data structure created is based on a combination of the ontology developed in a parallel research project [13] using the Protégé knowledge editor tool (see Figure 2), the project folder structure of a vacuum manufacturer, and findings from the literature. Implementing the lifecycle data structure in a PDM system would enhance process efficiency and improve information flow within the organisation.

The data structure developed has its foundation in the product-process-resource model described in the literature. However, the structure presented extends this model with project related information having as a result a project-product-process-resource model as it is shown in Figure 3. The 'project' element was added since this is a key mechanism applied within the case study company. Current product development programmes often include multiple products; a product family. Modular components and various project management resources are therefore referred to according to the project. Such a distinction makes a valuable addition to the practical element of operating a new product introduction programme, and does not detract from the relationships between products, processes and resources.

The upper level element 'lifecycle system' shows that the system represents a combination of project, product, process and resource to describe the entire lifecycle of the product. This top level element is missing from the literature studies where generally product is the central element.

The 'project' element contains information about marketing, project management, competitors and product family definition. The 'product' element describes the product, its architecture, BOM, and its components. The 'process' element of the data structure includes information about the design, manufacturing, service, logistics and disposal of the product. Service process information has been addressed by [14]; whereas manufacturing process information has been addressed by [13]. Finally, the 'resource' element of the structure integrates information about the facilities, person, equipment, information resource, fixture and raw material. The full data structure is depicted in Figure 4.

Figure 2. Protégé class hierarchy

Once the data structure was created, it was transferred into the PDM system Teamcenter Engineering. A collaboration context object – Vacuum pump Lifecycle system - was created as a top level element to represent the entire system. Then, immediately under the collaboration context, structure context objects were used to represent the project, product, process and resource. Finally, under each structure context, a folder hierarchy was created to collect and organise all the data and knowledge. Figure 5 shows the top level view of the data structure in Teamcenter Engineering.

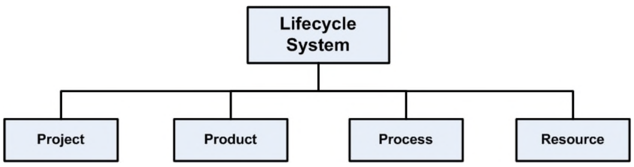

Figure 3. Top level of the data structure

5. SYSTEM COMPARISON

This section introduces the ontology editor – Protégé - and the PDM system – Teamcenter Engineering – used in this research. Protégé had been selected by the parallel research project as the ontology editor. Teamcenter Engineering was selected for convenience: Cranfield University has a fully functional installation available. PDM systems have significant costs associated with purchase, installation and support so this was the only available commercial scale PDM system. The two tools are significantly different mechanisms used to create, manage, share and reuse information and knowledge. Protégé is a free and open source knowledge system that allows creating ontologies, which can be used to represent data and knowledge related to the product. Protégé is a customisable tool that provides a total freedom to create, manipulate and interconnect knowledge bits. It is flexible and expansible, and there is a

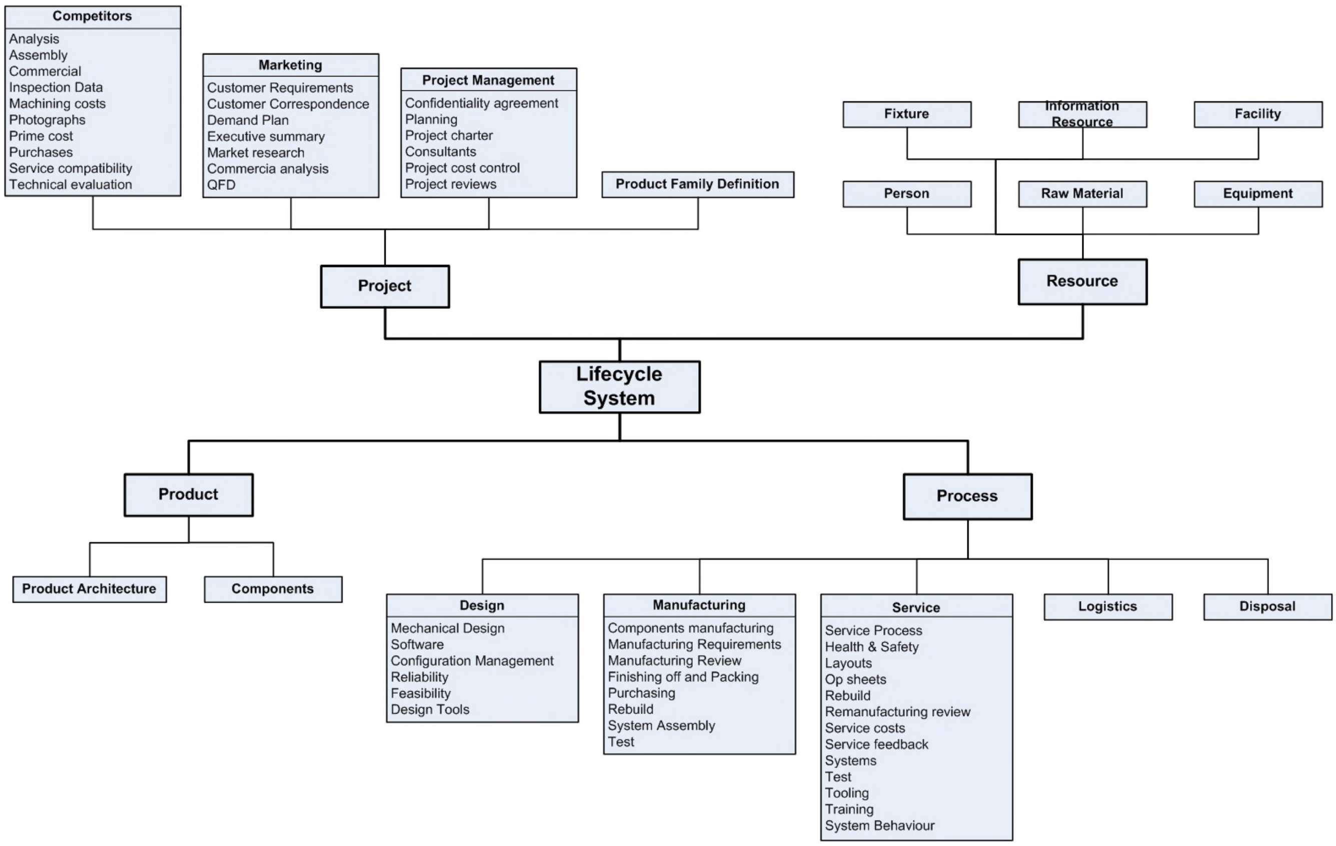

Figure 4. Data structure

wide number of plug-ins that can be included into the system. Moreover, it has no limitation in terms of class hierarchy, number of attributes of each class and knowledge interrelation. On the other hand, it is a centralised system which does not allow accessing at the same time to different. This means that it cannot be used as a collaborative tool. Another disadvantage of Protégé is that it does not allow attaching files. For this reason it can only store certain product related knowledge and data, character strings and numbers, but not specific product files such as specifications word documents, CAD files, hypermedia, etc.

Teamcenter Engineering provides a collaborative and distributed secure environment, allowing to multiple users the access to the tool at the same time from different locations. It allows the attachment of a wide variety of files, from word documents, excel documents and text files to CAD data. In addition, it permits creating data structures and workflows; and the visualisation of the attached files. On the other hand, Teamcenter Engineering is an expensive proprietary system, which although it can be customised in some manner, the users have not full freedom to personalise the different aspects of the system. The integration of knowledge is not an easy task and it has to be entered in document formats. Finally, although it allows referencing files, it is difficult to relate and link knowledge distributed across the whole data structure.

6. KNOWLEDGE INTEGRATION INTO PLM

6.1. Methodology for knowledge integration

PLM is a business strategy which embraces a wide range of tools to support the product lifecycle from the concept, through design and manufacture, to the disposal of the product. However, in today's competitive and global environment it is also crucial to support decisions with non product specific information related to each of the stages of the lifecycle. Organisations have to manage more efficiently one of their most precious assets, the knowledge. Thus, the integration of knowledge into PDM system has become a strategy to improve organisation's competitiveness in the business. The literature review revealed the growing importance of integrating knowledge management into PDM systems to support a collaborative and distributed product development environment. Recent studies have carried out the integration of knowledge base system and PDM system by means of programming languages to create interfaces between both systems or by using XML files to share the knowledge with the PDM system.

Nevertheless, this paper presents a methodology for the integration of design, manufacture and service knowledge captured by an ontology editor – Protégé – into the developed data structure in the PDM system without using any of the solutions described in the literature. This methodology is a generic approach, which means that it has to be customised every time it is implemented in order to adjust to the needs of the specific organisation's The methodology, which is depicted in Figure 6 comprises the following steps:

Step 1: Understand the need

The first step consists in understanding the need and future benefits that drives the integration of design, manufacturing and service knowledge into PLM, and ensure that every stakeholder gets involved in the process.

Step 2: Study the Knowledge System capabilities

Secondly, the knowledge system has to be exhaustively analysed. In this case, the knowledge system utilised – Protégé – is an ontology editor, and as such, ontology's capabilities had to be analysed.

Step 3: Analyse the Ontology

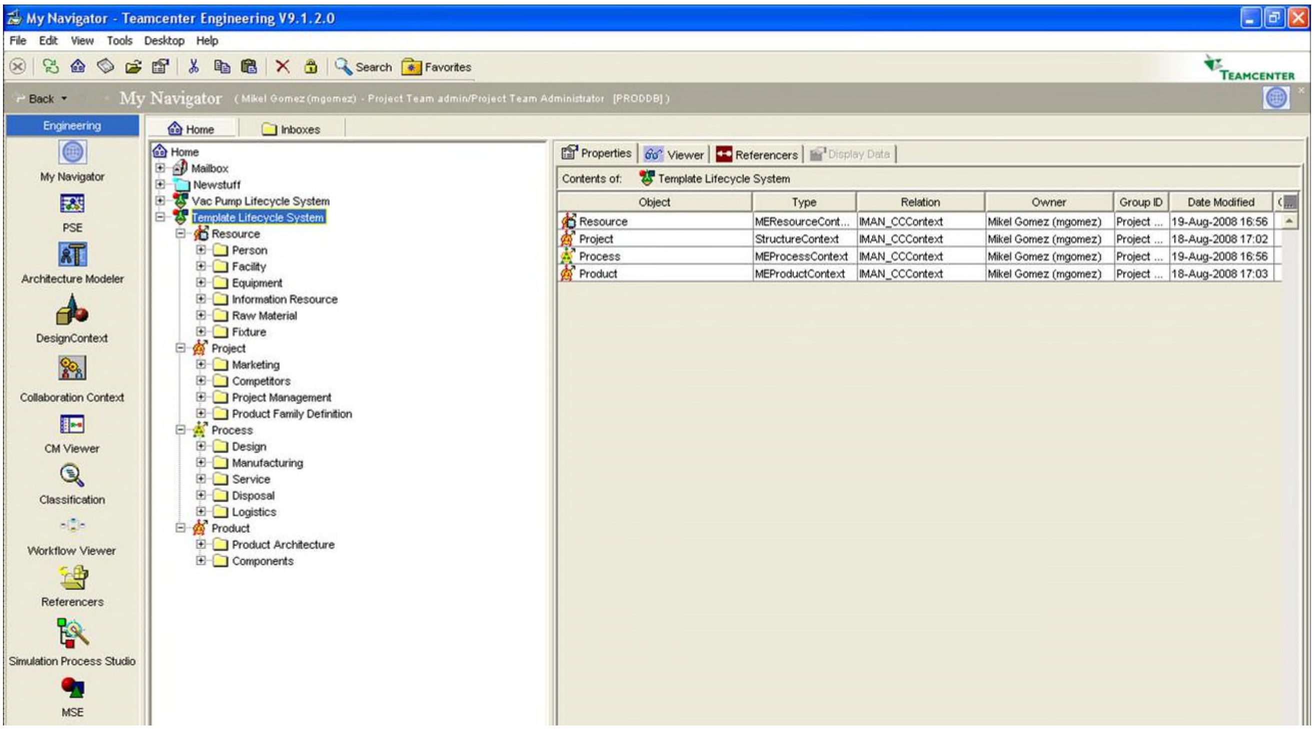

Figure 5. PLM Data structure: screenshot from the Teamcenter Engineering system

It is crucial to analyse the ontology, identifying the classes, their attributes, relations between the different objects and the constraints.

Step 4: Create the UML representation of the ontology

Once the ontology has been analysed, it is necessary to create the UML representation of the ontology which will help to identify in detail the classes, subclasses, their properties and the relations between them.

Step 5: Study the PDM system capabilities

The step number five consists in studying the capabilities, functionalities, types of object available and applications of the PDM system in order to identify the most suitable manner to integrate the knowledge.

Step 6: Identify and determine type of objects

The sixth step is crucial since it is related to the way of managing and representing the knowledge in the PDM system. PDM systems allow the creation of a number of different types of object. The most commons are items (i.e. to represent a product), datasets (to import documents of other applications such as Word), folders (to create the project hierarchy), BOM (to create the product structure), collaboration context, forms, etc. Thus, it has to be decided in which type of object is going to be translated each piece of the knowledge

Step 7: Integrate the knowledge into the PDM system

In this step, it has to be identified the best manner and location to include the objects which compile the knowledge in the current data structure in the PDM system. Eventually modifications to the data structure could be done to make the knowledge more accessible. Finally, the knowledge is integrated.

Step 8: Identify the cross-references / links

Once the knowledge has been integrated, some pieces of knowledge could affect, or could be necessary in different parts of the product structure due to the relation of product related knowledge across the entire product lifecycle. Thus, references to these knowledge pieces will have to be created in the required locations of the data structure.

Step 9: Validation with case studies

Once the knowledge has been integrated into the data structure, a validation from experts by means of organisation's real case studies in PLM is necessary.

Step10: Training

The training stage accelerates the learning process of the people involved in the PDM system.

Step 11: General use, maintenance and support

Finally, in the last step, the data structure with design, manufacture and service knowledge is in full operation and used by all the stakeholders; but this knowledge has to be properly managed and maintained by the people who use the PDM system. Thus, PDM system has to be used to capture, explore, share, reuse, manage and maintain the knowledge.

6.2. Knowledge integration into PLM

Then, the key step in the integration of the knowledge compiled in Protégé into PLM, is to determine how to transfer the knowledge to the objects available in the PDM system. Generally there is not a direct transition, so the implementer has to choose in what type of PLM object convert the knowledge. The class hierarchy or ontology structure can be translated into Teamcenter since the PDM system allows creating folders to organise the data. However, the knowledge contained in Protégé can only be included in Teamcenter if it is converted in files which can be imported in Teamcenter as datasets (word documents, excel files, text files, etc,) or if the knowledge can be transferred to one of the various form templates available in the PDM system.

In fact, this is one of the main limitations of PDM when including knowledge since it is not possible to attach knowledge to other files such as CAD files, drawings, BOM, etc. unless the knowledge is written in the description field of these files. The latter was considered as an inappropriate solution. So, when transferring the knowledge to PDM, the process consisted in deciding the most appropriate file type.

Some of the knowledge pieces integrated into PLM are product architecture, manufacturing and service processes, machining features, facilities and many others.

For example, knowledge related to the machining features was integrated by creating excel files, which included the tolerances of the feature, the magnitude, shape, scrap-rate and other parameters. On the other hand, knowledge about the facilities of the organisation including factory, shop, cell and station was integrated into Teamcenter as an excel file, named 'Facility'. Moreover, knowledge about the people of the organisation was integrated by means of an excel file, which incorporated information about the name, factory where it was placed, role, project and task. The Figure 7 shows the resource structure which includes the knowledge files related to the machining features, facility, people and tools in Teamcenter Engineering. Other knowledge pieces such as the product architecture were translated into a proper BOM in the PLM system.

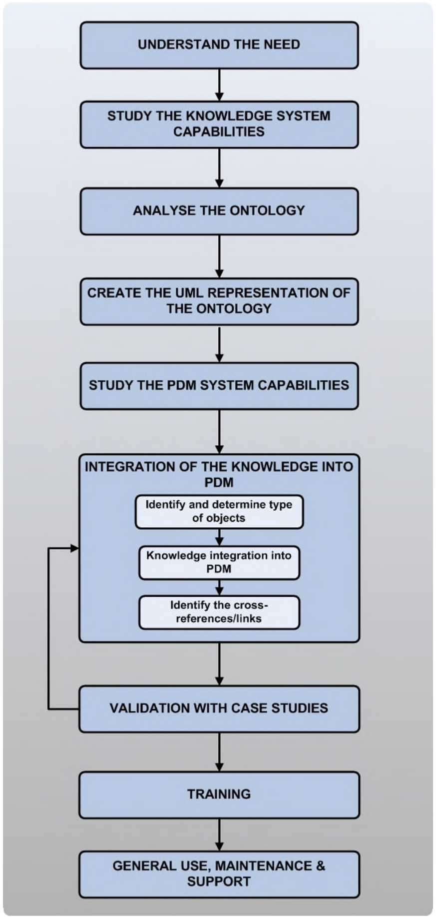

Figure 6. Implementing an ontology into PDM

7. SCENARIOS FOR PLM

In order to validate the implementation in PLM of the data structure, four scenarios related to the pump manufacturer business were developed. The first scenario simulates the release process of a particular product. The second one simulates the performance modelling of a pump. The third scenario deals with the development of a new product based on an existing pump. And finally, the last scenario shows how information resources can be shared among different products.

Focusing on the first scenario, it was decided to implement the release process in PLM because the AS-IS model of the vacuum manufacturer revealed that in the company it was done in a paper basis. This involved a large number of drawings to be signed by the different stakeholders, consuming a large amount of resources.

The release process is started by the project manager who initiates the workflow and decides who has to review the pump. Then, all the stakeholders involved in this process have to revise it and approve the design. Finally, if everyone approves it, the project manager applies the release status (see Figure 8).

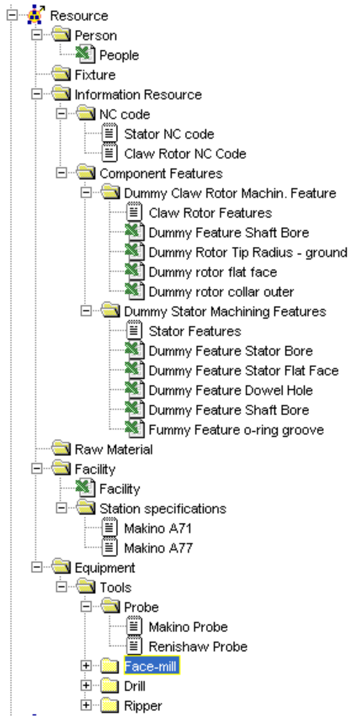

Figure 7. Knowledge integration example

In order to simulate this scenario in PLM, a workflow template was created. Then, once the release workflow template was designed, it was applied to a real product in Teamcenter in order to observe the benefits of implementing workflows in PLM. This PLM functionality allows tracking the current stage of the process and accessing to the target information (CAD data, specification docs, drawings, etc) involved in the activities the process is comprised of.

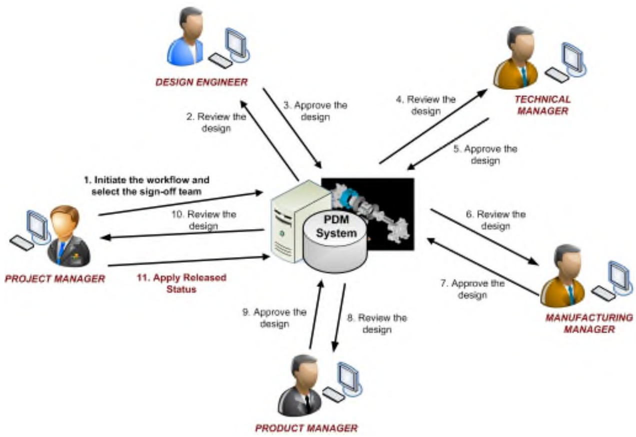

Figure 8. Release process

7.1. Validation

The PLM proposal was validated with four users from the case study company: two engineers and two from CAE systems. Two were carried out via email: respondents answered a questionnaire about a presentation describing the proposal. Two were carried out using web conferencing: respondents answered questions after a live demo. The respondents all stated that the implementation of the PLM data structure within the NPI process would offer significant benefit to the business. It was noted that the scenarios used for validation were simplistic, and did not therefore reflect the detail required in a live project. They also recognised that the cost and effort for implementation would be substantial, and so significant top management support would be required.

7.2. Limitations of the PLM proposal

The PLM data structure proposal was made on the basis of a limited case study: a small number of products, components, manufacturing data sets and processes were added to the system. In the case company, approximately 1% of the total components were added to the system (4 of 300). Coverage of knowledge within the proposed structure has therefore not been fully tested. However, the generic nature of the structure should allow for extension to new or unidentified areas. The effectiveness of the proposal has also not been tested in a live NPI scenario; such an effort would require substantial effort beyond the scope of this research.

8. CONCLUSIONS

Product Lifecycle Management (PLM) has revealed to be the approach to address the challenges today's organisations are facing, by improving the management of the intellectual assets, resources and processes across the whole product lifecycle. PLM implementation will lead to shortening time to market, process excellence, a reduction in costs, an increase of the revenues and a better relationship with customers, suppliers and partners.

Nevertheless, the deployment of PLM is not an easy task. Thus, having a standard data structure would facilitate the implementation and customisation of the PLM solution to the particular needs and requirements of a specific organisation. In addition, having a standard knowledge management embedded into PLM would improve the efficiency, enable process excellence and encourage innovation.

This paper has developed a data structure that integrates all product related information (e.g. CAD models, requirement documents, BOM, NC codes, etc), providing a standard repository of product data through all the stages of the lifecycle. This structure classifies the data into project, product, process and resources, and has been implemented into the PDM system Teamcenter Engineering, integrating data and knowledge from a vacuum pump manufacturer. This implementation has revealed the benefits of managing all the intellectual assets, including knowledge, in a collaborative and distributive manner.

In addition, the methodology developed to integrate knowledge from a knowledge editor into PDM is a new approach to embed through-life product knowledge into an existing data structure.

Regarding to the vacuum pump manufacturer, the AS-IS Model revealed that the current PLM implementation is not mature due to the lack of integration between the different systems and the few functionalities implemented in the PDM system, which is mainly used to store CAD data. For this reasons, in order to achieve process excellence, organisation's' PLM strategy should focus on the system integration and on the role of the PDM system as the foundation of the PLM environment.

In this context, the company would need to carry out three actions. First, it would have to develop a complete data structure template in the PLM system, which includes all the project files, and links between these files; secondly, the company would have to customise their PLM system by implementing the various functionalities the system provides (e.g. workflow templates, BOM); and finally it would have to improve the compatibility between all the systems that are part of the PLM environment such as the ERP system.

Finally, the implementation of these recommendations would require a huge amount of resources in terms of money and dedication, a reengineering of the organisation's processes, a change in people working philosophy, and a full commitment of every person in the company, from top management to development teams.

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