A Constraints Driven Product Lifecycle Management Framework

Julien Le Duigou[1, 2], Alain Bernard[1], Nicolas Perry[3], Jean-Charles Delplace[2]
[1]IRCCyN, Ecole Centrale de Nantes, 1 rue de la Noë, 44321 Nantes Cedex 03, France
[2]Centre technique de l'industrie mécanique, 57 avenue Félix Louat, 60304 Senlis Cedex, France
[3]LGM²B, Université de Bordeaux1, 15 rue Naudet, 33175 Gradignan Cedex, France
{Alain.bernard, Julien.leduigou}@irccyn.ec-nantes.fr; {Julien.leduigou, Jean-charles.delplace}@cetim.fr
Nicolas.perry@iut.u-bordeaux1.fr

Abstract
The management of the product information during its lifecycle is a strategic issue for the industry. In this paper, a constraints driven framework is proposed to create and manage the product information. The method proposes to each actor that intervenes on the product life cycle to act on the quote, the development or the industrialisation of the product. From each phase of the product lifecycle, the extraction, capitalisation and reuse of fundamental knowledge is coordinated by a generic meta-model. This paper explains this approach through experiments in three different SMEs of the mechanical industry.

Keywords:
Product Lifecycle Management, Knowledge Based Engineering, Information System

1 INTRODUCTION

Information is becoming the strategic resource for the 21rst century companies. To produce more efficiently, this information has to be shared with all the actors of the product development, including the external actors, such as suppliers or subcontractors. The firms connect more and more the other companies to their information system, and especially their PLM system. But only 5% of SMEs of fewer than 100 people use a PLM system to manage their product information [1]. Some problems exist that discourage the SMEs from going further in the integration of the digital extended enterprise.

To solve these problems, SMEs from mechanical engineering field need the implementation of specific methods and information system models.

In this paper, we will introduce first the scientific studies that will enable us to establish the starting point of our approach. Then we will present our research method, an inductive “research/action” approach, based on a spiral cycle structured on successive phases of analysis, development, experimentation, and then linking up with the methods and models enriched by experience feedback. The immersion phases will be described. They were organised in three different companies chosen with respect to a typology of the mechanical engineering SMEs. This immersion phases enabled us to specify the generic meta-model and the deployment method for a PLM system mainly dedicated to product data integration and management in extended enterprise.

2 STATE OF THE ART

In this chapter, different levels of the knowledge information system in the companies are presented: From the PLM as the backbone of an extended enterprise information system, to the integration of specific knowledge based systems.

2.1 The PLM concept

PLM is first an enterprise strategy [2]. It involves managing all the data concerning a product, throughout its life-cycle, and all the internal and external actors involved in the development of this product. CIM data define the PLM 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*” [3].

Much work has been done in this field, especially in the aeronautic and automobile sectors in order to propose technical data management methods [4, 5]. Some others try to address the SME specificities and propose solutions such as Delplace for sand casting foundries [6].

2.2 Knowledge management

The management of knowledge was always done in an implicit way, today it becomes a volunteer approach. Knowledge management can be define as “*a systematic, organized, explicit, and deliberate ongoing process of creating, disseminating, applying, renewing and updating the knowledge for achieving organizational objectives*” [7].

Lots of methods such as MKSM and MASK [8], CommonKAD [9] or MOKA [10] are proposed to help the knowledge engineer in the development of knowledge based systems. Those knowledge based systems automate expertises, but those expertises still need to be integrated in the PLM paradigm.

2.3 Integration

The works to improve the integration of different jobs of the design in the approach of product development are numerous. The more represented jobs are the production process such as machining [11], stamping, foundry [12], forging [13, 14]. Others are focused on simulation stage [15, 16], maintenance or dismantling.

Lots of jobs are integrated in the product development approach. But all the job applications are not easily connectable to a unique system. A solution is to translate a specific model in a standard model [17], as STEP (Standard for the Exchange of Product model data) [18, 19], or other from different projects, such as IPPOP [20].

2.4 Conclusion

We notice that the majority of the works done about PLM and the integration of the different jobs about product development are applied in assembly industry, mainly automotive or aircraft companies. So the proposed research approach is based on immersions in the SMEs of the mechanical engineering field in order to extract the needs in terms of PLM that are not covered by the actual software.

3 RESEARCH APPROACH

The proposed approach is based on a methodology in order to structure and manage the product data of extended enterprise. To define these methods and to reach a common approach for the different companies, an inductive three-step research approach have been implemented:

- Immersion: needs analysis and integration of specific methods.
- Generalization: creation of a generic approach.
- Validation: experiment of the approach, back to an extended enterprise.

3.1 Immersion: needs analysis and integration of specific methods

The first phase relies in interviews of companies to extract their practices in terms of digital and collaborative engineering and the best practices of implementation. Moreover, we bench the PLM software tools to list the functionalities and their ability to meet SME needs.

The pilot companies, representative of the mechanical industry and their common requirements were selected. Then, immersive periods have been achieved into the different companies in order to directly and inductively integrate the technical data structuring and managing methods. This phase was coupled with the implementation of the methods with real data in the companies to verify the gap between the proposed approach and the objectives.

3.2 Generalization: a generic proposal

In this phase, based on the analysis of the different pilot companies, the method of managing product data has been generalized, and a meta-model has been created. This approach is compatible with the standards and is applicable to all the types of companies in the mechanical industry so that it may be used in an extended enterprise context.

3.3 Validation: experiment of the proposal

The experiment feedback will test, improve and validate the proposed Information System structure. Tested in an extended enterprise environment, the implementation method will be verified and also its suitability to the requirements of product data management.

4 IMMERSION IN COMPANIES

In this paragraph a typology of companies is proposed in order to choose the pilot companies for the immersive periods. Then the initial situation is explained and the proposed approached is implemented in one company of each SME category. Then, those immersions are assessed.

4.1 Typology of mechanical engineering SMEs

The choice of the pilot companies was achieved through a typology that characterises the main categories of SMEs in the mechanical engineering field. It was necessary in order to obtain results that allow us to generalize the proposed approach within an extended enterprise.

Differentiation axes were chosen: the number of parts that forms the product (produced by the SME). Indeed, the companies with a large number of parts by product often manage BoM to master their product data. At the opposite, the companies with a little number of parts by products manage routes and operations to master their product data. And last, some companies manage both BoM and routes. Thereby, the proposed classification is based on these three types of SMEs (Figure 2).

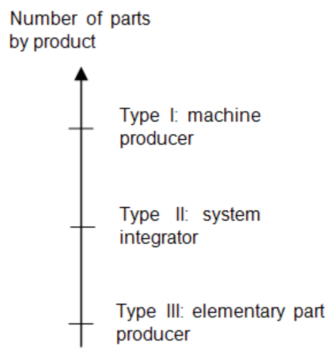

Figure 2: Typology of mechanical SMEs

This typology classifies the different companies present in an extended enterprise, from the toolmaker to the integrator, through all the intermediaries. From this classification, three companies covering the three zones of our typology were chosen as pilot companies. By analysing the needs of these different companies, their generic needs were extracted (the needs that are not specific to the activity of the company) and aggregated in order to obtain the specifications of the proposed generic model for the extended enterprise.

The next case studies must enable us to put into practice methods of technical data structuring and management, adapted to those specific companies. In order to do this, the analysis of the needs of the company in terms of PLM was achieved. Then, a specific approach has been proposed to improve the initial situation. And finally, this method has been validated by integrating a specific solution in the company.

4.2 An equipment manufacturer: PSL CONCEPT

4.2.1. Description of the company and initial situation

The PSL CONCEPT company produces and sells equipment for ships. Among these products, there are reserve rudders, pulleys and tackles, sheaves, jam cleats and various accessories. This is a type II company ("system integrator").

This company organizes the main part of its products into families. In fact, as many system integrators and equipment manufacturers, its products are made from standard products, to which options and modifications are added to meet customer needs.

After the audit, it seems that the main needs in this company are as follows:

Knowledge capitalisation: An improvement of design, resulting from customer feedback, a set of tests or the optimization of the designer, are not reproduced on the other products of the family without the involvement of the designer on each product. This process is lengthy and is a source of error.

BoM management: The BoM (Bill of Material) management is manual and the BoM have to be updated when there is a major modification of the product design.

Reference management: Due to the diversity of existing products (1200 references only for pulleys), the product references are hard to manage efficiently.

Quote: Giving a precise quote of a new product is complex because it is difficult to know the quantities of raw materials that will be consumed and the manufacturing time before the detailed design of the product.

Archive management: When a client comes back with a product, it is not always easy to find the original drawings of the product that has been sold with the references of the different parts.

Thus the audit phase underlines the main PLM needs of this company. Based on these first needs, an approach is proposed to give a global solution to these needs.

4.2.2. Proposed approach

The design of a pulley passes through the choice of technological solutions that respond to a set of technical and economic constraints. Those constraints are knowledge of the extended enterprise that are formalised to be used by the designers.

The customer's needs are incorporated in the model using constraints: The constraints related to the production capacity, the constraints linked to the product, the constraints linked to the suppliers. The set of those constraints is coupled with the parametric CAD model of the pulley.

The customer chooses a certain number of variables that activate the relating constraints. Then a solver proposes a solution that responds to the set of constraints.

4.2.3. Integration of the approach

The study focused on a major and well-known family of products for the company: the pulleys.

The different functions of the family were broken down, and then a set of functional dimensioning parameters were created for the products in order to link those parameters to the different functions.

Thus, if a function is not required by the customer, and if this function is only linked to a single sub-product, then this sub-product will not be present in the final product. Moreover the modification of a functional parameter leads to the modification of the design parameters which are linked to it.

When a modification of the design is made, this modification is implemented on all the products of the family that use the function are concerned by the modification. There is no longer information loss when a product is improved because if the function or the definition of the design parameters is modified, all the products of the family will be automatically modified and so have the benefit of the improvement.

A system of significant referencing was introduced based on the functions of the product family

A table for the quotes was also made to calculate the price of a pulley depending on its functionalities. Each function has a cost. Adding all the costs of the functions required by the customer we obtain the base for the determination of the global quote of the pulley.

A global approach of structuring and managing technical data has thus been defined, which enables us to create a software solution to automatically design a family of products and to meet the company needs [21].

4.2.4. Conclusions on PSL Concept

The implementation of the software based on this approach and the results that we have obtained (the design time for a new pulley has gone from hours to minutes) prove that the proposed approach is in phase with the needs of this kind of company, an equipment integrator (type II), in the mechanical industry.

The link between function and product appears clearly. The use of functional constraints to express the need of each SME of the extended enterprise in the PLM system is a possible way of improvement for the integration of SMEs.

4.3 An elementary part manufacturer: Capricorn

4.3.1. Description of the enterprise and initial situation

The second pilot company is named CAPRICORN. This company manufactures crankshafts, connecting rods and pistons for the up market automotive industry and racing cars (F1, Nascar, 24H du Mans, Rally…). It is a type III company in our typology: "elementary part producer".

This kind of company has problematic manufacturing technical data. The elementary part manufacturers directly receive their drawings and CAD models from their customers. Then they add their expertise to draw up the plan of procedure of the product and produce it.

The audit phase makes us focus on the following initial situations:

External exchange: The customers directly send the CAD files to the engineering department, mostly in STEP format. When a modification occurs, a new file is sent by the customer. The modification must be done manually on the documentation in the engineering and planning department.

Knowledge capitalisation: The first phase of a route is quite repetitive. CAPRICORN would like to have software to automate this phase in order to be able to launch the supply earlier.

Documentation: The operations of a route need documentations from the production department. They are manually done and it is time consuming and a source of error.

Internal exchange: Once the documentation is made, it has to be sent to the manufacturing department. If a modification occurs, the right version must be sent to this department.

The following paragraph proposes an approach to respond to those needs.

4.3.2. Proposal

Such as the design of a product, the creation of a process plan is a serial of choice of solutions that respond to a constraints group.

Each actor involved to the creation of the process plan must be able to intervene and to add his own constraints.

The customer expresses his constraints through the geometry of the part. The subcontractor has a set of possible surface treatments. The supplier got a limited set of diameter for is blanks. The shop floor is composed of a certain number of machines, more or less charged, with specific capacities…

The resolution of the set of constraints allows to partially define the operations that compose the process plan of the product.

4.3.3. Integration of the approach

The study is focused on the historical product of the company: the crankshaft (Figure 4).

Based on a preliminary analysis, it has been decided to structure the technical data in three groups. The information from the product, directly extracted from the STEP file, the information from the work centres and the craft rules, both collected during the audit phase.

It is supposed that the macro process plans are already known. In a chosen route, each operation uses the information of some specific faces of the product, the tooling machine information and the craft rules to create the detailed operation.

With a face recognition based on fundamental knowledge, it is possible to find the different entities cut in each operation.

From the final 3D model product, the blank part geometry is reconstructed. Then each machining operation is simulated by a feature of machining. As a result the 3D model of each intermediary part is obtained.

From these detailed operations, drawings are generated with the intermediary dimensioning, tolerance and a full title block.

Then these drawings are saved and sent to the production department.

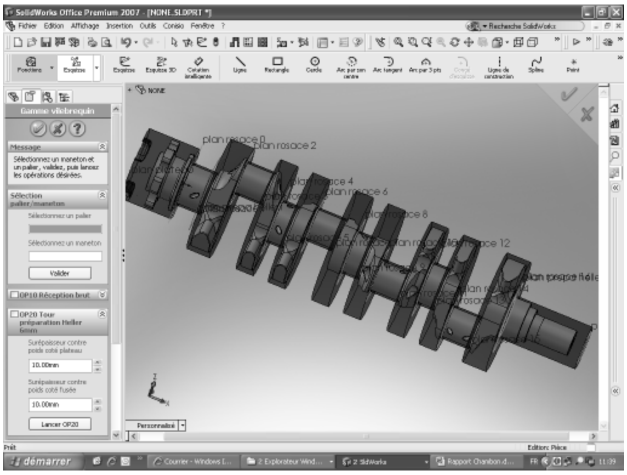

Figure 4 –Interface of the software

4.3.4. Conclusion on CAPRICORN

This case study enables us to identify the different technical data used by the process planning department during the industrialisation phase. It also enables us to extract the knowledge to use those data internally as well as externally via the exchange with the customer and the production department.

The integration of the process plan management and the intermediary part management is essential to this kind of company. It is possible to use standard, such AP 214 from STEP to formalise the objects and the data use in this example. So the integration of the process plan in the PLM is essential to the integration of the elementary part manufacturer in the extended enterprise.

4.4 A machine producer: SMP

4.4.1. Description of the enterprise and initial situation

The third case study company is SMP, a grinding machine producer. This company is a type I, “machine producer”.

Due to the high number of components of its products and its high customisation, this type of company often encounters bill of material (BoM) problems.

After the audit phase the following initial needs have been selected:

BoM creation: Actually, the BoM are done manually from the analysis of the CAD model using a spreadsheet and sent to the manufacturing department.

BoM management: When a modification occurs, in a sub-assembly, the operator has to detect all the impacts. He manually applies and checks the modifications to all the BoM that are impacted.

BoM structuring for the production department: The production department and the engineering department have two different ways to structure the BoM. So the modifications of the engineering BoM are more difficult to impact on the production BoM and vice versa.

BoM integration in the ERP: The integration of the BoM in the ERP of the company is done manually, which is time consuming and source of error.

The next paragraph will explain which approach was integrated to improve the initial situation.

4.4.2. Proposal

As it has been seen in the two previous examples, the constraints are putting forward by the different actors of the development of the product to define a design problem. To let these actors being able to integrate the constraints by themselves, without the intervention of a knowledge engineer, the constraints have to be integrated in the specific product model of each actor.
Then the design department expresses its constraints on a structure that is copied from the CAD structure and the production department expresses its constraints on a structured copy on the ERP structure. Those constraints are expressed on the same product. The set of constraints allows the definition of the problem to be solved.

4.4.3. Integration of the approach

The approach proposed here is based on a double view of the bill of material. Using a buffer file without the structuring of the product, we can have a different structuring in each department of the company.

First of all the different information needed by the engineering and the production departments are selected. Then, a list of attributes is made for each kind of products, sub-assemblies and assemblies.

Then a BoM is created for the engineering department extracted from the list of attributes only those wanted by this department and with the same structure as the 3D model.

A second BoM is created for the production department extracted from the same list of attributes only those wanted by this department and with the same structure as the ERP model.

If a modification occurs in the attributes, both, the engineering and the production BoM will be automatically changed.

If the change is made on a sub-assembly or a part, all the assemblies containing the sub-assembly or the part are updated.

4.4.4 Conclusion on SMP

This case study enables us to identify the technical data that are transferred between the engineering department and the planning department in this company.
It also allows us to extract the knowledge useful to their transfer and especially concerning the multi view of a product. This multi-view notion has been applied using a buffer file that contains all the information of the product, the structuring of the product being specific to each view.
If the works on BoM management problem in PLM are already consistent, the notion of multi view and partial view are always a source of improvement to the integration of SMEs.

4.5 Conclusion on the immersions

During this phase of immersion a knowledge management approach has been integrated with first of all an extraction of fundamental knowledge, then a structuring of that knowledge and finally its integration into the software. The validation of this work was done by software tests carried out by the expert. The results of those tests go back to the knowledge extraction phase, then another structuring and integration phase, and so on until the desired results are obtained.

Knowledge extraction: The first phase of each immersion was an extraction of the data used by the expert and the rules used to process them. To obtain that information two methods were used:

- Observation of the expert during his work: The observation of the expert allows us to get a first look at the use of technical data in the company. The dialogue with the expert enables us to extract the explicit knowledge inherent to his job.
- The practical aspect of the expert's job: To refine the knowledge about the use of those data, we actually did his job, using his workstation. We extracted the implicit knowledge that was not formalised by the expert.

Structuring: The integration of those methods needs the structuring of the technical data by group (objects and attributes) and the structuring of the craft rules by algorithms.

Integration: The automation of those methods integrates the technical data and the craft rules into some software validated by the company.

Obviously the specific application integrated in the pilot companies are too specialised to be directly integrated into a generic model for the extended enterprise. Some of those data and some processes are really specific to the product manufactured by the company or to its production process (sheave diameter or number of crank pins may not be generic attributes of a product). Nevertheless some other can be processed in a global way in the extended enterprise [22].

The next chapter will generalize the different approach uses in each case study to generate a global approach applicable to the whole extended enterprise.

5 A GENERIC METHOD BASED ON A PPRO META-MODEL

5.1 Aggregation of the specific model

By aggregating the three class diagrams of the three pilot companies, we obtained a meta-model that can be applied to the pilot companies, and by extension, to each SME of the mechanical industry that have the same product data problematic. The creation of this meta-model is not described here; it is the subject of an entire paper in progress at the present time.

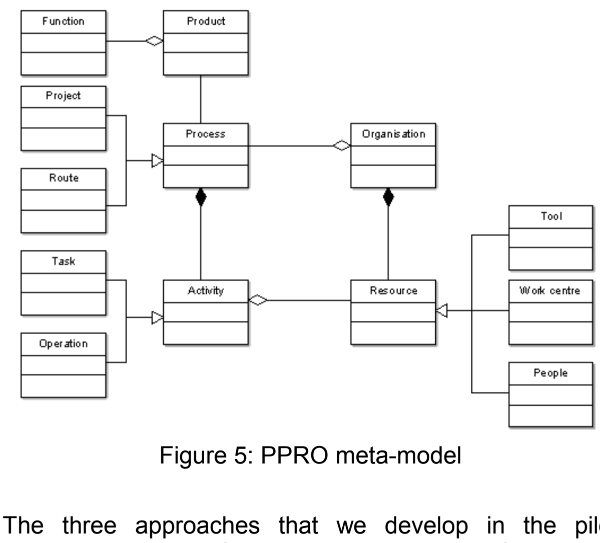

Figure 5: PPRO meta-model

The three approaches that we develop in the pilot companies are transferable to the meta-model figure 5.

5.2 Aggregation of the specific method

The specific method of each pilot company was to add constraints on the objects linked with the focus of the studies, and then to solve the problem as a Constraints Satisfaction Problem.

In the case study PSL Concept, the design of the product is chosen by constraining the function, the process and the resource. The product attributes keep being variable. By solving this system, we obtain the value of the parameters of the 3D parametric model.

If the product and the resources are fix and the process variable, then the resolution of the system gives information about the attributes of the process. In the case study Capricorn, the resources and the product are fixed and the process variable. By solving this system we obtain decision aid on the process planning.

The case study SMP doesn't deal with the resolution of a problem, as the design of a product or a process planning creation. This case study explains the filling of the problem parameters, like the product attributes. Each actor of the development of the product can add his own constraints in the system.

The method consists in solving a system expressed by adding constraints to the model. So by constraining some objects of the system and letting some others variable, the system can be solved to partially define the variable object.

To fill the meta-model in order to have all the attributes of the system product process resources that are fixed, each actors of the product development put his own constraints.

When the system is full, the change of one constraint from the customer, the operator, a supplier… changes one or more variables values of the system, ie of the product or the process or the organisation…depending on what it is considered as variable and what is considered as fix.

6 CONCLUSIONS AND PERSPECTIVES

The next contribution will be the explanation in detail of the PSL Concept case study resolution with the generic method. This study will allow the explanation of the resolution concept used to solve the system.

As explained in the research approach, those method and model will be then validated by a second experimentation phase with the integration of a collaborative tool base on this meta-model in an extended enterprise.

The last point is to map this PPRO meta-model with other existing models and methods to be able to focus on the specificity of the SMEs extended enterprise to be able to find in other existing models where are the missing points to the model to be applied in a SMEs context.

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