INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

AN EMPIRICAL STUDY OF REQUIREMENTS RELATED TO GENERIC PRODUCT STRUCTURES IN CAD-PDM INTEGRATION

Kati Sarinko, Roy Björkstrand and Asko Martio

Keywords: CAD, generic product structure, product data management, product family, systems integration

1 Introduction

Usually product development creates and manages product data with many different systems, such as CAD (Computer Aided Design) and PDM (Product Data Management) systems. CAD systems are mainly used for designing and modelling products [Baba, 1998] and PDM systems for managing product data [Crnkovic, 2003]. These systems are usually integrated so that data is automatically transferred between the systems [Eigner, 2001]. One important industrial trend is the increasing use of mass-customisation, which can be realised with product families. A *product family,* is defined as a large set of end products (variants) constructed from a smaller set of components within defined product architecture [Erens, 1996]. A product family can be represented with a *generic product structure* [Erens, 1996].

This paper investigates the special requirements for CAD-PDM integration when developing product families with generic product structures and the conceptual solution for the requirements. The paper also considers a detailed technical solution, which, however, is not implemented in this study.

The paper is structured as follows: the motivation and previous work is described in Section 2, methods and materials are described in Section 3, results are described in Section 4, discussions and previous work in Section 5, and the conclusions in Section 6.

2 Motivation and Previous Work

Some considerations on the benefits and challenges when integrating CAD and PDM systems can be found in the literature [e.g. Eigner, 2001] and also there are many technologies and standards (e.g. RosettaNet) available to implement the integration in detailed level [e.g. Nurmilaakso & Kotinurmi, 2004]. This research, however, has not considered the integration of systems if the company develops product families with generic product structures. The problem area is challenging because functionalities for supporting product families in different CAD or PDM systems are different, which also makes the integration much complex. There is a lot of demand in the industry for considering this kind of issues, because PDM and CAD systems are very common these days and companies have also started to produce product families.

This section gives an overview on the previous work. Because the research question of this study has not been considered earlier, we'll try to give an overview of the phenomena around it: generic product structures, PDM systems, CAD systems and systems integration.

2.1 Generic Product Structures

A product family can be represented with the *generic product structure* [Erens, 1996]. All components of the different variants are represented in one structure. Components in the generic product structure can be common, alternative or optional. Alternative and optional parts are equipped with configuration rules. Configuration rules define what to include in a product. Variants are represented as *instances* that are generated from the generic product structure. Erens [Erens, 1996] has defined Generic Product Structure (GPS), which describes product families with traditional product structures. He recognizes two types of product structuring concepts: primitive generic products and compound generic products. Primitive generic product cannot be further decomposed into generic products. Compound product is composed of primitive generic products or other compound products. The product families are described with a specification, which consists of parameters and parameter values. GPS is a hierarchical structure and the elements in a structure can be either abstract or physical. Configuration constraints in the Generic Product Structure prohibit combinations of parameters. The configuration constraints can be expressed with the Boolean logic.

2.2 PDM Systems

A PDM system is a tool that helps engineers to manage product data and product development process. PDM system keeps track of the product data and information required to design, manufacture and maintain products. The main functionalities of the PDM system are data vault and document management, workflow and process management, product structure management, classification and program management. PDM system makes correct data accessible to people and systems that need the data. It shares the most recent approved information. PDM information model could be utilized with object-oriented approach and it consists of the basic object-oriented elements; objects, attributes, classes and class hierarchy and inheritance. PDM system architecture consists of a metadata database and data items managed by the system but stored in an ordinary file system. Product structure management in a PDM system usually allows management of generic product structures. [Crnkovic, 2003]

Usually a PDM system is integrated with a CAD system and ERP (Enterprise Resource Planning) systems [e.g. Eigner, 2001]. Integration with other systems also exists, such as product configurator system, SCM (Supply Chain Management) system SCM (Software Configuration Management) system and CRM (Customer Relationship Management) system [Crnkovic, 2003].

2.3 CAD Systems

Computer Aided Design (CAD) systems are used to design and document products. CAD-systems can be divided into two-dimensional (2D-CAD) and three-dimensional (3D-CAD). Backgrounds and utilization of these are totally different requiring different fundamental approach to design problems. The possibilities to transfer data from design to production are also different. [Baba, 1998 and Laakko et al., 1998]

Generally 2D-CAD is an electronic version of hand drawing with some assisting features such as symbol libraries. Main utilization of 2D-CAD is on the area of production document creation (drawings, BOMs). Though during 2D-CAD's history the systems have evolved to meet many special design needs, the 2D-CAD system still lack some features needed due to the system philosophy and possibilities, such as geometry data transfer to Computer Aided Manufacturing (CAM), associative links between documents, dimension (constraint) driven geometry, easier design of multi-curvature surfaces, visual representations of geometry (rendering). [Baba, 1998]

For better performance on these problem areas, 3D-CAD's were developed. 3D-CAD is based on the mathematical model representing the unambiguous geometry of product that is referred in document creation, used in other systems for special engineering actions (FEM, CAM etc.) through geometry transfer and for collaborative actions. Main difference between 2D-CAD and 3D-CAD can be seen in drawing creation. In 3D-CAD, a view in drawing is referred as associative child of the model enabling fast and reliable changes. A change, that can be done through modifying parameters of the model, is automatically updated in drawings. Other typical difference from 2D-CAD is that 3D-CAD has structures. Assemblies contain subassemblies and parts, which contain features. All these objects form hierarchical structure often called a model structure. The storing of 3D-models can be of type "one file" or "each object in own file". Today, multi file systems are taking over since there are certain advantages, for example in sharing of models and in computing performance. [Laakko et al., 1998]

To manage and share the CAD models among team members in product development phase so called Team Data Management (TDM) or Engineer Data Management (EDM) systems can be used instead of using enterprise level PDM described in chapter 2.2. These systems, usually are provided by CAD vendor. Advantage of TDM is tight integration to CAD system. Usually TDM is used to manage early phase of product development when the need for iteration of design is high. After the items are relased, they are transferred in PDM system. [Eigner, 2001]

2.4 Systems Integration

Integration between the systems increases efficiency by improving data flow and reducing human errors. Integration also reduces the need for personnel involvement during the processes and extends data accessibility. The major cost saving comes from savings in data entry costs, cost of office supplies, personnel cost and communication cost. There are usually many reasons for integrating systems such as corporate mergers, growing global competition and the e-commerce movement are forcing companies to be more efficient and effective. There are also risks in integration: cost is a major factor and implementation can take many years and management of different technical standards may be difficult. [e.g. Huang et. al., 2003: and Lim and Wen, 2002]

There are several standards, such as RosettaNet, that helps to implement integration by standardizing what information to share, when and how to share the information. RosettaNet use XML to e.g. define standard messages exchanged between partners. XML provides flexible information structuring with a formal syntax, which describes the dependencies between objects, elements and attributes. [Nurmilaakso & Kotinurmi, 2004]

There are two types of integration methods for CAD and PDM integration; CAD application integration and Data integration. CAD application integration is a method of integrating the user interface of a CAD system with a PDM system. For example is the file is opened in the CAD system, the file is automatically checked out from the PDM system. Data integration assumes that the CAD application integration already exists. This data integration provides more detailed data transferring between the systems. For example, PDM system is able to extract or update information contained in the CAD files, for example item attributes. This enables PDM users to access the data without having to open CAD files in the CAD system. Some integrations enable product structure information extraction. It is possible to transfer assembly-subassembly-components/part level information. [Eigner, 2001]

3 Methods and Materials

Case company was Patria Vehicles Oy, which focuses on marketing, product development, manufacture and integration of armoured wheeled vehicles as well as their life cycle service. Customers include defensive forces in many countries. The company is located in Finland and employs 400 people. Patria Vehicles Oy has two different product families, 6-wheeled and 8-wheeled vehicles. The case product was the XA-series of armoured wheeled vehicles, which is the 6-wheeled product. Patria Vehicles Oy delivers 5-14 different variants of XA-series every year and the total amount of product individuals is 80-120 per year.

This study was done during larger co-operation development project at Patria Vehicles Oy. The project started in October 2002 and ended in June 2004. The project consisted of many smaller tasks such as configuration management, product structure management, change management and product data requirements for 3-D modelling. During that time, Patria Vehicles Oy also started a 3D-CAD evaluation project. We used information we have learned during this larger co-operation project as the basis of this study. This study started in February 2004 and ended in June 2004. We had seven meetings during the spring 2004 at Patria Vehicles Oy.

We used case study as the research method [Patton, 1990]. First we interviewed the experts from the product development and IT department and studied the existing documents on product data management and systems. These interviews were done during project meetings and there were five specialists from the product development and IT department who participated in all these meetings. The roles of these persons were development manager, configuration manager, engineering support manager, engineering designer and system support manager. We studied their existing practices on product data management, how they are now managing generic product structures, in which systems, process descriptions and learned the functionalities of the existing PDM system and overall information of CAD systems. Then we analysed the data and defined the special requirements. The requirements are based on the interviews with the specialists and existing documentation. Finally, we determined conceptual and technical solutions for the requirements.

To ensure that all the relevant data was considered during this study, we recorded the interviews and discussions and collected the necessary documented product data. After the interviews and discussions, we listened to the recordings and took notes of the most important information.

4 Results

In this section the results of this study are described. We defined the special requirements when developing product families with generic product structures, analysed the alternative approaches of conceptual solutions, specified the most suitable conceptual solution and determined the detailed technical solution.

4.1 Present State Case Study

Patria Vehicles Oy has become aware of the importance of the system integration. Business requirements are high because the quality requirements of the product are defined by NATO (North Atlantic Treaty Organisation). All the documentation and processes have to be clear and effective. Without good integration, work has to be done manually, which causes many mistakes and takes much time. There are also a lot of competitors on the market and therefore it is very important to have good tools and processes to provide products as profitably as possible.

Patria Vehicles Oy has Aton PDM system to manage product data. They also have a 3D-CAD system in use. They are evaluating a new CAD system because the existing one is not responding to the new requirements. The old CAD system do not provide company with well-managed product changes and effective re-use of designs. The models are created during initial design phase and model based drawings are generated in prototype phase. After this, the drawings are exported to the PDM system. Because of this, the link to models is broken and design changes and re-use of designs is on 2D-basis. Modelling techniques used in old CAD system result in extra work and incoherence in structures. The old CAD is "one file" type and the actual assembly structure is not built.

The product family is described with a generic product structure. All the needed components and sub-assemblies are described in the one generic structure. All parts with no rule are constant parts and exist in all variants. If the part is optional, the rule defines when the part can be selected. Alternative parts have the same position number and a condition, which defines when a particular part can be selected. There can be several levels in the generic product structure and alternative or optional parts can exist in each level. An example of a generic product structure is presented in Table 1. There are 9 alternative parts with the same position number 01. Each of these items, which are different motors, has item number, description, quantity and condition. The condition describes parameter values for selecting a particular part. For example item 89734549 is a motor with 11 kW nominal power and with the voltage 1000 V. It is selected if the nominal power is 11 kW (PO=11) and voltage is 1000 V (U=1000) and drive motor type is electric (DR="E").

Table 1. Example of a generic product structure.

34543X Final assembly

Pos	Id	Desc	Qty	UoM	Condition
Assembly identifiers					
	345431	Machinery, hydr. drive, 8 kW			PO=8 and DR="H"
	345432	Machinery, hydr. drive, 11 kW			PO=11 and DR="H"
	"ORDER"-34543X	Machinery, electric			DR="E"
Assembly parts					
01	89730919	MOOT.7,5kW 3000rpm 400/690	1	pc	PO=7 and (U in (380;..;440) or U in (660;..;690)) and DR="E"
01	89731929	MOOT.7,5kW 3000rpm 500/50	1	pc	PO=7 and U in (500;..;575) and F=50 and DR="E"
01	89734269	MOOT.7,5kW 3000rpm 1000	1	pc	PO=7 and U=1000 and DR="E"
01	89734139	MOOT.7,5kW 3000rpm 500/60	1	pc	PO=7 and U in (500;..;575) and F=60 and DR="E"
01	89727679	MOOT.11kW 3000rpm 400/690	1	pc	PO=11 and (U in (380;..;440) or U in (660;..;690)) and DR="E"
01	89734419	MOOT.11kW 3000rpm 500	1	pc	PO=11 and U in (500;..;575) and DR="E"
01	89734549	MOOT.11kW 3000rpm 1000	1	pc	PO=11 and U=1000 and DR="E"
01	89553729	HYDRAULIMOOTTORI 8 Kw	1	pc	PO=8 and DR="H"
01	89762919	HYDRAULIMOOTTORI 11 Kw	1	pc	PO=11 and DR="H"
02	80091609	6-RUUVI	4	pc	DR="H"
03	85128189	LUKKOALUSLEVYPARI	4	pc	DR="H"
04	80091729	KUUSIOMUTTERI	4	pc	DR="H"
05	37720178	KANNATIN CT10H	1	pc	PO=8 and DR="H"
06	80019409	6-RUUVI	4	pc	DR="H"
07	85106809	LUKKOALUSLEVYPARI	4	pc	DR="H"
08	80082149	KUUSIOMUTTERI	4	pc	DR="H"
09	30977358	HYDRMOOTT ASPALA CT12	1	pc	PO=11 and DR="H"
10	37905748	TUKIJALKA CT3B H	2	pc	PO=11 and DR="H"
11	37905618	APUAKSELI CT3B H	1	pc	PO=11 and DR="H"
12	37732101	RUNKO-OSAT CT3	1	pc	
13	37732201	JÄÄHDYTIN KP CT3	1	pc	
14	44277690	6-RUUVI	4	pc	PO=7 or DR="H"
21	81356309	KUPARITIIVISTE	1	pc	
22	85647329	SUORALÄHTÖ SISÄK	1	pc	

4.2 The Special Requirements for the CAD-PDM Integration When Developing Product Families

Three main special requirements for the CAD-PDM integration when developing product families with generic product structures were identified:

(1) **The management of the configuration rules.** The configuration rules in the generic product structure define which parts are selected into particular configuration. These rules have to be managed in some system. Management of theses rules has to be easy. Defining and updating these rules should be understandable without modelling language skills.

(2) **The generation of instances from the generic product structure.** When generating instances from the generic product structure, the 3D models of that instance must be uploaded and linked to the instance structure for documenting purposes.

(3) **The addition of variants to the generic product structure.** Sometimes there is a need to add new variants to the product family. It might be a new component or some bigger entity. The generic product structure must then be updated with new components and rules. It is also necessary to create new 3D-models of these new parts with the CAD system and add them into that product.

4.3 Different Conceptual Solutions Approaches

Different conceptual solutions for these requirements were defined and analysed:

(1) **The management of the configuration rules.**

- Managing the rules in the PDM system.
- Managing the rules in the CAD system.
- Managing the rules with an external configurator.

(2) **The generation of instances from the generic product structure.**

- *Configuration information is stored in the PDM system. An instance is configured in the PDM system and information is transferred to the CAD system, where an instance structure is generated from the generic product structure (Figure 1).* Configuration information is created and stored in the PDM system. The instance is configured in the PDM system and configuration information is transferred to the CAD system via "text-file". Configuration information is a list of attributes and parameters, which defines the instance. There must be an auxiliary application between PDM and CAD system, which interprets the configuration information to form the corresponding the CAD model of instance. Some synchronisation is needed between configuration information and generic product structure. The unique instance documents must be linked to instance structure in the CAD. The main advantage is that if the products are simple, the structure management might be easier in the CAD system than in the PDM system. The challenge is that this solution requires that auxiliary application and developing such a system might be difficult.

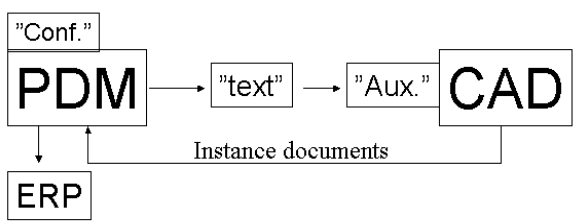

Figure 1. Configuration information is stored in the PDM system. An instance is configured in the PDM system and information is transferred to the CAD system, where an instance structure is generated from the generic product structure.

- *Configuration information is managed and an instance structure is generated in the PDM system (Figure 2).* Configuration rules are created and stored and the generic product structures are managed in the PDM system. The instance structure is then transferred to the CAD system and CAD system uploads the 3D models of the instance and links them to the instance structure. The advantages of this solution are that existing PDM system has already functionalities for managing the generic product structures and configuration rules. The use of that PDM system is familiar. The challenge is that when CAD system gets the instance structure and tries to upload the models of that structure, the location information of these models might be missing or it may be difficult to define.

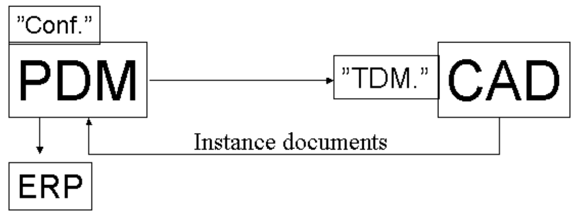

Figure 2. Configuration information is managed and an instance structure is generated in the PDM system.

- *Functional level configuration in the PDM system and detailed configuration in the CAD system (Figure 3).* In this solution the PDM system does not manage generic product structure. PDM system manages functional level structure that is "filled" in the CAD system using CAD specific product family and parameterisation rules. The PDM has basic functional level configuration rules. This "sales configuration" is transferred to build a CAD model and to provide necessary information for detail configuration on sub-assembly level. The advantage is that if the detailed configuration is made in the CAD system, it is possible to check the correctness of the instance structure and the models. The main challenges are that if the rules are distributed, is might be difficult to define which rules are managed in the PDM system and which are managed in the CAD system. Also the modelling languages of the configuration rules are usually different in these systems and that might cause misunderstandings.

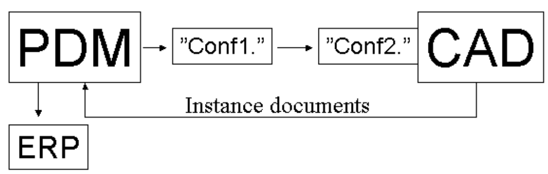

Figure 3. Functional level configuration in the PDM system and detailed configuration in the CAD system.

- *Configuration and instance generation in the CAD system (Figure 4).* In this solution the CAD system manages the configuration information and generic product structures and creates the instances. The instance structure with documentation links is then transferred into the PDM system. This solution requires that either product is simple or configuration rules are not numerous because the tools in the CAD system to manage configuration rules are unsophisticated.

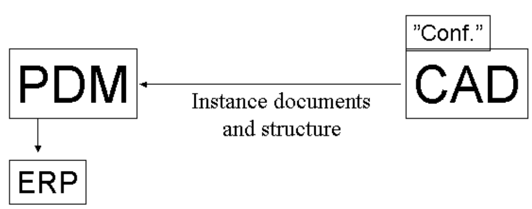

Figure 4. Configuration and instance generation in the CAD system.

- *Configuration in external configurator system and structure is then transferred to the PDM or CAD system (Figure 5).* In this solution the configuration information is managed in the external system. The list of attributes and parameters, which defines an instance, is then transferred to the PDM or CAD system. Then the rest of the process is similar than described above, depending on which system the configuration information is transferred. This solution may be feasible if the PDM and CAD systems do not support configuration information management properly (for example the rules are difficult to define and manage) or do not have such a functionality at all, or if there is a process or organizational need to keep this activity separate (for example if there is a need to do configuration by laptop). The main challenge is that is there is one system more and also one integration more to manage.

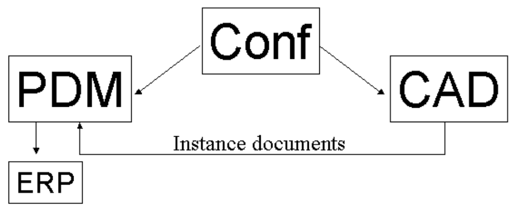

Figure 5. Configuration in external configurator system and structure is then transferred to the PDM or CAD system.

(3) **The addition of variants to the generic product structure.**

- New variants (items) and their configuration rules are defined in the PDM system. The new generic product structure is transferred to the CAD system. This method is suitable for cases of "few parts missing" but requires tight integration that can upload models and fill the model structure with empty files for CAD work.

- The 3D models and items of new variants are developed in the CAD system and the items are transferred to the PDM system to be added to the generic product structure. Then the configuration rules for these new items are created in the PDM system. This method is suitable in cases where the variant requires a lot of development "from the scratch". No special integration functions are needed.

4.4 Conceptual Solution

The following solution was considered the most suitable:

(1) **The management of the configuration rules:** The configuration rules are managed in the PDM system. Each item in the generic structure has a configuration rule, which indicates when the item can be selected. If the item is included in all instances, the configuration rule is empty. The PDM system has the tool for creating and maintaining the configuration rules.

(2) **The generation of instances from the generic product structure:** An instance structure of the variant is generated from the generic product structure in the PDM system. The instance structure is then transferred via integration to the CAD system. Each existing item has a 3D model in the CAD system. The CAD system builds a 3D model of the product instance from the 3D models of the items in the instance structure. Locations of the models are determined with coordinates or relations.

(3) **The addition of variants to the generic product structure:** If the new variant consists of purchased items, a new variant is added to the product family by adding the items and configuration rules of the new variant to the generic product structure in the PDM system. Then the new generic product structure is transferred to the CAD system. The CAD designer can then create the 3D models for the new items. After the designer is

finished, he/she saves the 3D models in CAD system. The attribute information of the 3D models for the new items is then updated via integration to the generic product structure in the PDM system.

4.5 Detailed Technical Solution

The solution was realized with Aton PDM as a top administrative system. Other systems were an existing ERP system and the new 3D-CAD system. The new 3D-CAD system provides also TDM functionality and integration was implemented by integrating TDM and Aton PDM systems together. The PDM system and the existing ERP system had been already integrated and this integration was used for transferring data from the PDM system to the TDM/CAD system. The main reason for using this PDM-ERP integration was that the port for sending information from PDM already existed.

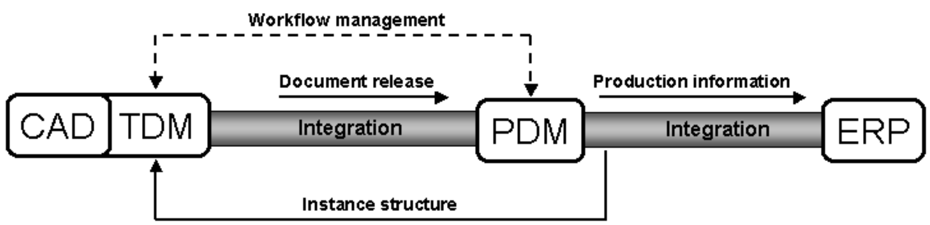

Figure 6. Simplified picture of the PDM-CAD integration.

The 3D models are stored in the TDM, and the files, such as drawings, portable document formats (PDF formats) and lightweight geometry presentations (JT formats), are released and transferred to the PDM system. TDM has its own item series for product development objects that allows the designers to create iterations without increasing the amount of items in the PDM system but still manage and share them in context of "CAD-users". Only released items are transferred and published to the PDM system. PDM system will then manage versions, revisions, workflow and status of these published TDM items. The extra files (PDF's and JT's) are created during publishing from the TDM to the PDM system. Standard items (purchased items) and configuration rules for all items are created in the PDM system.

In the figure (Figure 7) is an example of adding a new variant (item) to the generic product structure (1-3), generating a new instance structure from the generic product structure (4) and uploading the 3D models of that instance and linking them to the instance (5-7).

(1) The items for the new variant are modelled in the CAD system and using TDM as a data management tool. Items and documents get TDM specific item code.

(2) The TDM items and the documents are transferred to the PDM system.

(3) The new PDM items are added to the generic product structure and configuration rules are defined.

(4) Using configuration utility of the PDM system, an instance structure is created.

(5) The instance structure is uploaded to the CAD system. The models of the instance are defined based on the location information by using TDM searching tool.

(6) The uploaded 3D models of the instance are documented (e.g. assembly drawings) in the CAD system. The documents are linked to the instance structure.

(7) The instance information is then transferred and saved in the PDM by using existing ERP-PDM integration.

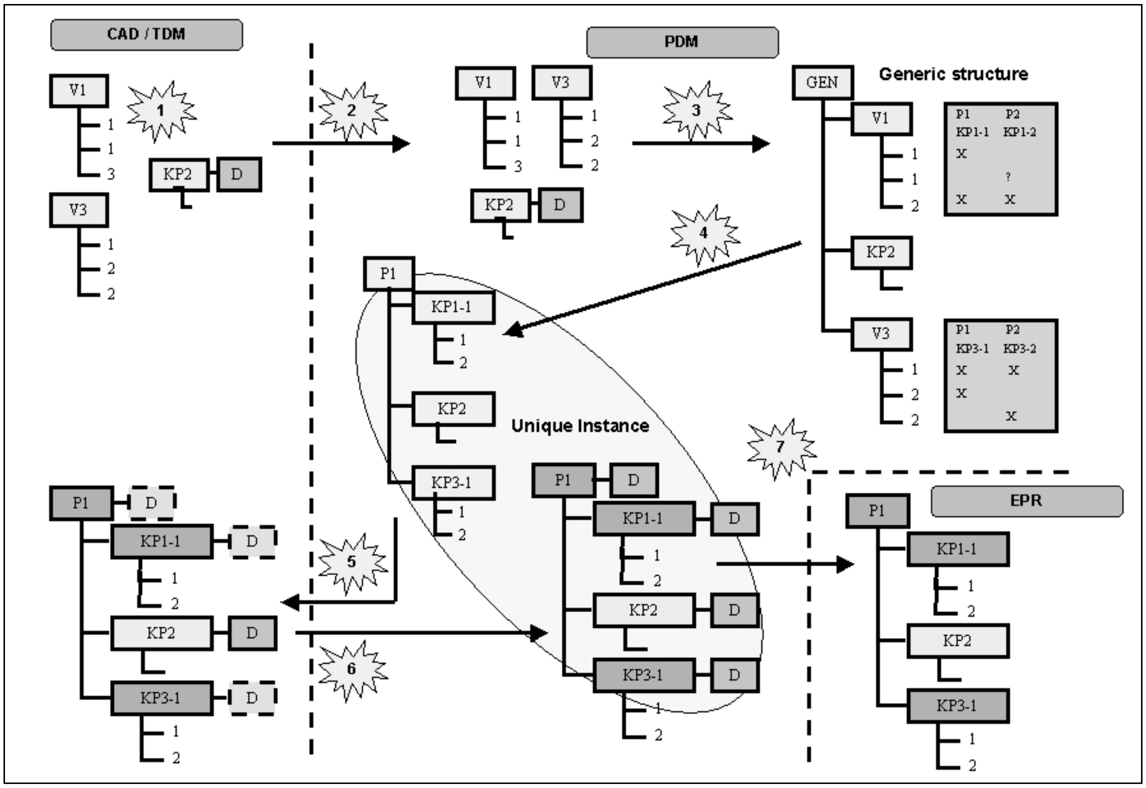

Figure 7. Technical solution for CAD-PDM integration.

The main challenge for the technical solution is that the integration link between ERP and PDM is highly customised and if there comes new versions of these systems, the integration has to be done to work between the new versions.

5 Discussions and Previous Work

The need for integration exists because for example without good integration, work has to be done manually, which causes many mistakes and takes much time. We learned in the present state case study the structure and the functionality of the existing generic product structure and how the existing PDM system manages these structures. With the interviews we defined the requirements for the integration and defined conceptual solution and detailed technical solution. The research method was sufficient for defining requirements in the case company. Validity of these results is based on the high experience of the interviewees. The employees who participated in this project were highly skilled and they have very good experience on company's practices, needs and also on the systems used. Commitment for making this integration really work as well as possible was high.

There were three main requirements for the integration when developing product families with the generic product structures. These requirements do not depend on the details of the generic product structure, such as the notation for configuration rules. Rules must be managed and there must be processes for generating instances and adding new variants regardless of the level of the intagration between systems. Conceptual solution depends on what kind of systems are available and how the company is organised and what would be the best solution for that particular company. Existing environment affects the solution. Detailed technical solution is normally based on the best conceptual solution, but usually when the integration is implemented technically, some compromises or customizations are necessary. As a result, teh implmentation may be less elegant than the conceptual solution.

As mentioned in the previous work (Section 2) there is hardly any research available on the requirements when developing products families with the generic product structures but the industry has recognised the importance of product families and generic product structures as well as the need for PDM and CAD systems and their integration. Many technologies for integration between the systems have been developed. We can say that the integration between the PDM and CAD systems has been recognised in overall level and implementation methods have been developed. Our research considers issues between these two levels.

It seems that there will be a lot of demand for such kind of research in the future. Especially many companies are interested in practices for defining and implementing the integration between PDM and CAD systems. If the company develops product families, the integration issues are much more demanding and there is no common practices how to do that on the requirements level. This paper aims at giving some ideas on issues related to the topic. Naturally the results should be further validated and strengthened with more case studies in different companies with different systems.

6 Conclusion

In this paper, we investigate the special requirements for CAD-PDM integration when developing product families with generic product structures and the conceptual solutions for the requirements. The paper also considers detailed technical solutions, which, however, are not implemented in this study. The results are derived from a case study in a company that delivers products developed with generic product structures using CAD and PDM systems for creating and managing the product data.

When product families are represented as generic product structures, there are special requirements for the integration: the management of the configuration rules, the generation of an instance and the addition of new variants. The conceptual solutions and the detailed technical solutions for the requirements depend on the existing systems, their customisations, product families, which are developed, and processes and practices of the company.

This study addresses an important aspect of CAD-PDM integration. The results should be further validated and strengthened with more case studies in different companies with different systems.

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Kati Sarinko
Helsinki University of Technology, Software Business and Engineering Institute
P.O Box 9210, FIN-02015 HUT, Finland
Phone: +358 9 451 5161
Fax: +358 9 451 4958
Email: Kati.Sarinko@hut.fi
www.soberit.hut.fi