LAPPEENRANNAN TEKNILLINEN YLIOPISTO
LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

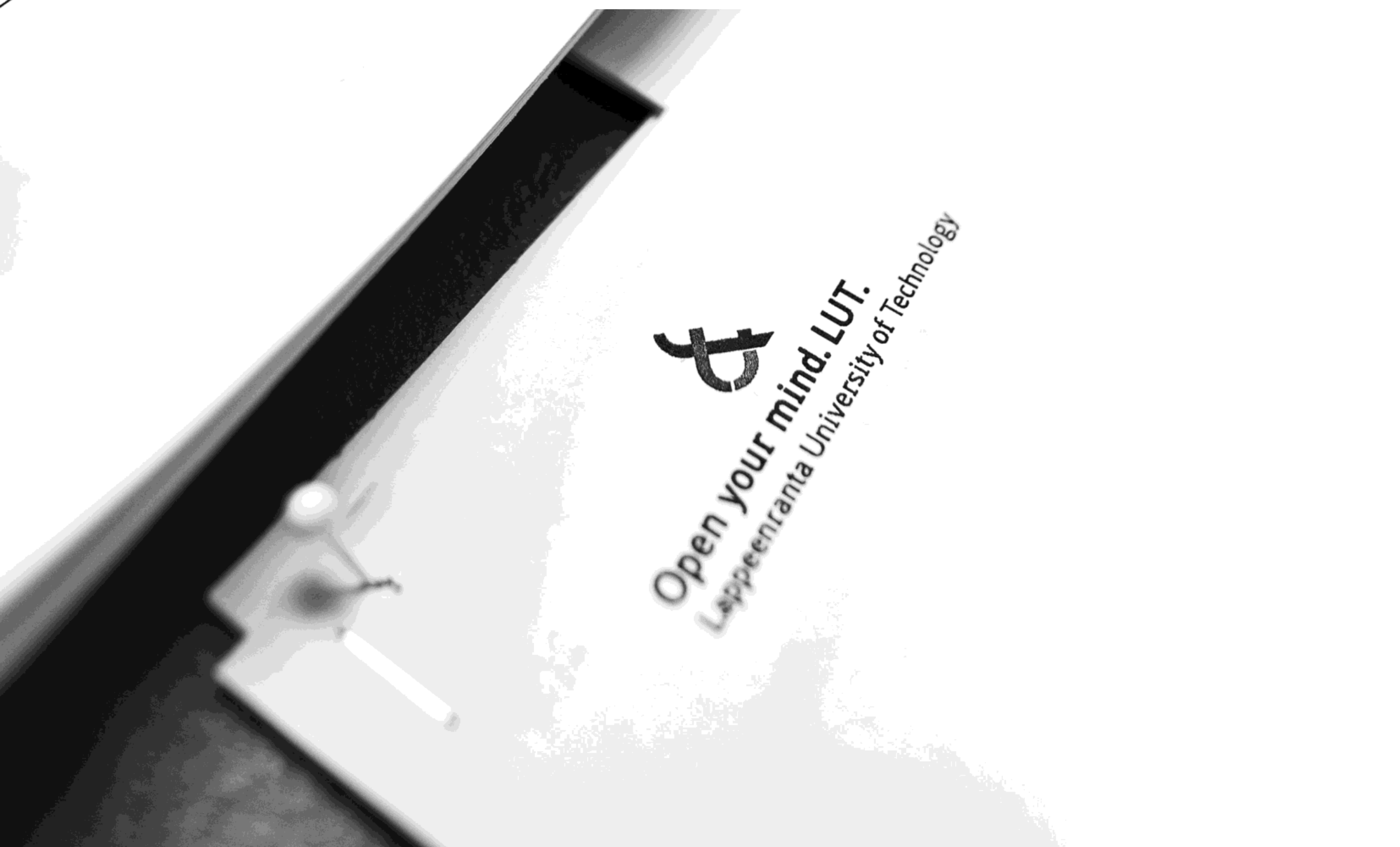
Teknillinen tiedekunta
LUT KONE

Faculty of Technology
LUT Mechanical Engineering

LUT Scientific and Expertise Publications
Tutkimusraportit – Research Reports 4

Merja Huhtala, Harri Eskelinen (editors)

Proceedings of the PDM2013 conference, LUT 24.-25.4.2013



Lappeenranta University of Technology
Faculty of Technology
LUT Mechanical Engineering

LUT Scientific and Expertise Publications
Tutkimusraportit – Research Reports 4

Merja Huhtala, Harri Eskelinen (editors)

Proceedings of the PDM2013 conference, LUT 24.-25.4.2013

Lappeenranta University of Technology
LUT School of Technology,
LUT Mechanical Engineering
PL 20
53851 LAPPEENRANTA

ISBN 978-952-265-386-4
ISBN 978-952-265-387-1 (PDF)
ISBN 978-952-265-388-8 (memory stick)
ISSN-L 2243-3376
ISSN 2243-3376

Lappeenranta 2013

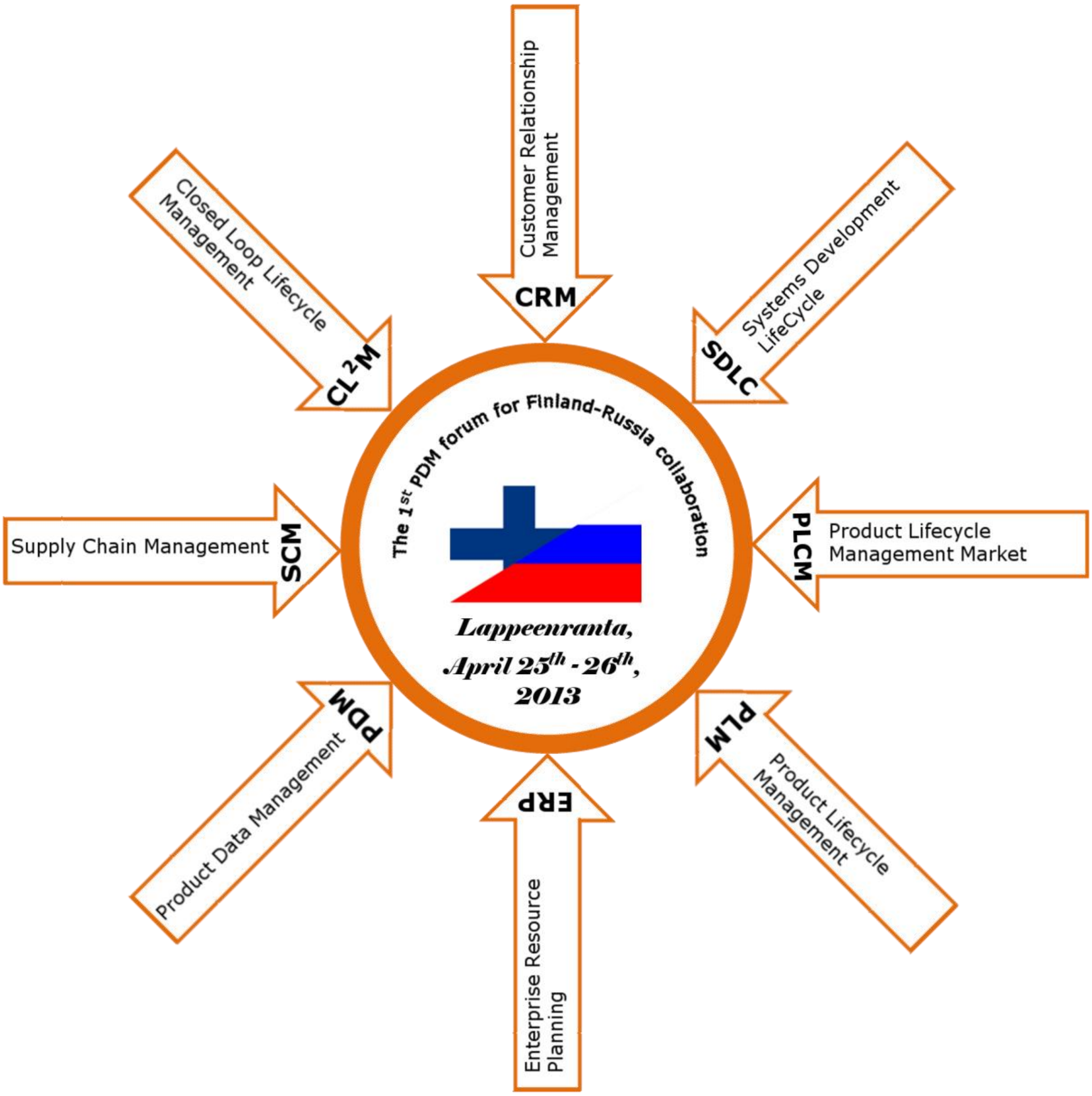

Customer Relationship Management
CRM
Closed Loop Lifecycle Management
CL²M
Systems Development LifeCycle
SDLC
Supply Chain Management
SCM
The 1st PDM forum for Finland-Russia collaboration
Lappeenranta,
April 25th - 26th,
2013
Product Lifecycle Management Market
PLCM
Product Data Management
PDM
ERP
Enterprise Resource Planning
PLM
Product Lifecycle Management

Table of contents

FOREWORD

The 1st PDM Forum for Finland-Russia Collaboration was held at Lappeenranta University of Technology, Finland, during 25.-26.4.2013. The forum brought together leading academics, practitioners, advisors, engineers, industrial experts, and software vendors from Finland and Russia.

The forum can be seen as a new integrating element between Russian and Finnish industries and universities. Over border connections between Russia and Finland may also bring new contacts and ideas to develop and expand businesses. Meeting different universities professors, PhD students, and companies' agents facilitates the sharing and discussion of current PDM (Product Data Management) issues.

We were fortunate to open this premier forum with presentations of the new advances and research results in the fields of PDM. In addition to tackling the most commonly debated global challenges and other related areas of research, the proceeding also included articles dealing with such fields as:

- PDM in the metal industry
- The PDM environment regarding effective subcontractor co-operation
- PDM application for global networks
- Successful industrial PDM examples
- Novel applications and the advantages of software applications
- Integration of PDM systems with design tools
- New scientific advances dealing with the development of PDM-systems.

The articles published in connection with the proceeding are divided into three groups based on their viewpoints. The first group focuses on product data management (PDM) and product life cycle management (PLM) theory. The second group includes detailed experimental scientific descriptions dealing with advanced technological areas, and new material science applications. The third group presents concrete industrial PDM applications.

GROUP 1: PDM AND PLM THEORY

This book discusses PLM from many viewpoints. One viewpoint is constructed in the context of globally networked manufacturing companies. In this particular context, the future challenges in globally networked manufacturing companies will be discussed. Based on the results presented in this book, one perspective could be that the manifestation of PLM is a PDM system.

The authors of selected conference papers have devoted considerable attention to the selection of most suitable and reliable research methods and methodologies for studying PLM and PDM systems. The common opinion of the authors seems to be that studying the success of the implementation of both PLM and PDM is a complex task. One possibility might be an adaptation of the Qualitative Comparative Analysis method.

In this book, the theory of design and development of production systems is also discussed. This discussion leads to a presentation of the advantages of how to utilize simulations in the context of production systems. Some key aspects from product design and strategic business processes, which have an influence on the design and development of production systems, are presented. This is done in order to justify the interaction between the product related information, which originates from e.g. PDM systems, and the business processes, and focuses on issues such as customers, markets, and competition.

One of the articles in the first group discusses what kinds of requirements the utilization of modularization, configuration or product families places on PDM/PLM systems. Probably the most important question is whether the information related to the module system is defined. This problem is discussed in further detail in which the discussion includes the architecture, modules and configuration knowledge, interfaces and partitioning logic of the product. To these five elements, different kinds of PDM information are also related. However, this information should be managed by using the PDM system.

One reason for organizing this PDM conference was originally the fact that new information systems have gained a constantly strengthen role in manufacturing industry. The discussion covers such areas as the execution of Enterprise Resource Planning (ERP) or PDM systems, and the development and utilization of modern production machines or control architectures. To open this discussion, in one of the articles the concepts of scalable, lean, and extendable manufacturing execution system (MES) are clarified. This paper outlines the challenges, which industry has fortunately recognized: we need PDM/PML/ERP systems that are agile enough to adapt to the dynamically changing environment.

Another change, which the articles presented in this book raise, is that project based manufacturing is moving towards lifecycle business in global networks. Furthermore, this presents challenges to companies when managing their businesses in this new type of operating environment. This viewpoint requires open minded discussion regarding the characteristics of project based manufacturing.

This book presents a theoretical framework for improving product information management in project based manufacturing business. This new framework is based on the literature review. The new framework provides the starting point for a systematic approach and useful tools to improve product information management.

Based on the results, it could even be considered that because it is so difficult to create the perfect solution, which would solve all the needs of product information management in a changing world, whether it should be accepted that the improvements of product information management be seen more as a process towards the target.

We have included in this book an article that analyzes how the different aspects of design, manufacturing, and assembly (DFMA) are included in the overall PLM model and what the appropriate content of PDM information is needed to support this overall model. Nine different perspectives are briefly discussed:

- Applied DFMA rules and guidelines for different manufacturing technologies in PDM systems
- Integration of DFMA evaluation forms, and production time calculation techniques with PDM
- Utilization of modularization, standardization, and platforms for PDM
- Development of advanced manufacturing processes and PDM
- Determining the most suitable manufacturing technology
- Utilization of feature-based systems
- Integrated approaches for controlling and managing both the design and assembly processes and their costs
- How to handle the development of material science and new material alternatives
- Utilization of feedback from maintenance.

This book highlights that the PDM system bridges the gap between design and manufacturing in a controlled and standardized way in order to manage both prototype design and changes in an existing product. This paper underlines the fact that although the viewpoint of DFMA seems to emphasize the technical product data of the PLM system, it is also necessary to remember the business-oriented aspects.

The articles, which have been selected for publication, also include a paper which discusses the aspects of spare part selling in the context of PDM systems. It is common knowledge that spare part selling has become an important factor for companies. As regards spare parts, it is important that the PDM works as it should; without a correct PDM the PLM does not work and tracking of an old product may even be impossible and thus it becomes hard to sell the spare parts. Knowing how the PDM system could work and what kind of information it is possible to add to the system are the key elements for success. For these reasons, this paper also discusses the working areas of PDM and PLM. The border between these two systems is sometimes unclear which might lead to a malfunction of the IT-system or a lack of information.

GROUP 2: ADVANCED TECHNOLOGICAL AREAS

This book includes a number of papers in which important aspects of manufacturability and productivity are discussed from the perspective of welding and laser processing applications, as well as advanced material science (such as composites, ceramics, nanomaterials). These papers include important knowledge and exhaustive experimental research results on such topics as:

- supersonic cold gas-dynamic spraying (CGDS)
- advanced crack-tip opening angle (CTOA) test and instrumented drop-weight tearing (DWT) test techniques
- a numerical model of a drop weight tear test (DWTT)
- electrochemical doping of surface during oxidizing (EDSO)
- laser technology synthesis of composite materials based on nanostructured powder materials

The applications of CGDS deals with the product data, which plays a key role, for example when manufacturing protective coatings. The new advanced material testing techniques are important when trying to manage the quality aspects of advanced materials as part of the PDM system e.g. thermomechanically controlled and processed (TMCP) steels. One example given is the application of DWTT to ensure the reliability of the applied materials in gas pipeline applications in cold undersea conditions. According to the test results, presented in the book, the EDSO method is suitable for e.g. ceramic coatings, which are formed of titanium. An interesting detail is that the presented method of ceramic coatings (e.g. titanium dioxide/corundum) produces coatings which are cold resistant. Laser processing data dealing with nanomaterials can be seen as an essential part of PDM data. This data could consist of the optimum magnitudes of the laser power, the substrate scanning speed, the powder feeding rate and the distance between the laser beam passes. The experimental result data for these variables is presented in this book. One of the articles in this group describes the unified methodology of design of a composite pressure vessel in the concept of PDM. The article presents an algorithm, which is based on a multi-criteria optimization procedure and the parameter space investigation method (PSI).

GROUP 3: INDUSTRIAL APPLICATIONS OF PDM

The book presents both academic and industrial viewpoints in the wide discussion area of PDM systems. Many articles are based on studies of globally or locally operating companies. The spectrum of analyzed companies includes examples from marketing, engineering, production, maintenance, and areas of specialized technologies. In the discussed examples, the variety of the products is also wide. However, the main question seems to be, what are the future PLM challenges of global companies?

One remarkable industrial case example is presented by Wärtsilä (Finland). There is an article in the book, in which Wärtsilä’s journey is explained when investing in a PDM system with a target of sharing one source of data and information amongst the different organizations within Wärtsilä as well as the external design companies. This article includes valuable descriptions of

- expectations about the outcome of the PDM project
- the PDM vision
- a user survey, and the goals and benefits
- the planning phase of the project and

- the PDM concept work model.

In addition, the PLM concept and process are also described. As discussed earlier, our industrial partners also state that the overall PLM development has been abstract and very complex.

Another industrial example comes from the Hartela Company, Finland. The book includes an article which describes how PDM and software automation are applied in a construction development project. The starting point for the work presented in this article is the need to find alternative practices for making substantial modifications to new constructions. The question is justified by dealing with how these changes are handled in a cost-effective way. This article concludes, once again, with the observation that the needs and requirements caused by product changes are complex and therefore require several methods of data management.

The conference has the great honor of presenting some highlights from this book regarding the material database developed by specialists from FSUE CRISM (Russia Federation). They have developed this database of materials and, in addition, also the list of suitable production technologies especially used for these materials in polar regions. The suggested system not only provides the most user-friendly information storage but also an information management system for various suppliers and different metallurgical products, which is designed for operation in northern regions. Presently, the database summarizes data on shipbuilding and building steel grades made in Russia for the Arctic region. The items contained in the database include product names, their producers, chemical composition of materials, and the mechanical material properties according to national and international standards. It is obvious that there is a necessity for good integration between PDM systems and these kinds of databases.

The articles in this third group strengthen the perception that there is a continuous need to search for sufficient and relevant information types and content for effective PDM/PDL systems, in order to build an acceptable balance between the data management aspects and the productivity aspects of the product.

On behalf of the Organizing Committee of the PDM Forum we would like to express our gratitude to all the authors, keynote speakers, participants, guests, organizers, and supporters.

Lappeenranta 25.4.2013

Juha Varis	*Harri Eskelinen*	*Merja Huhtala*
Professor	*Associate Professor*	*Secretariat and*
Honorary advisors	*General Chair*	*Publication Chair*

Applying of the Protective Coatings on the Welded Aluminum Riser Pipe Sections

A.A. Deev[1], A.F. Vasilev[1], R.Y. Bystrov[1] and A.N. Belyakov[1]

[1] Federal State Unitary Enterprise Central Research Institute of Structured Materials "Prometey"
Saint-Petersburg, 191015, Russia
victorm@crism.ru

Abstract

A well-known gas-thermal and plasma methods of applying powder coatings assuming the heating of dispersed particles up to the melting temperature, their acceleration by the flow and transportation to the surface. In the transportation process the complex, as a rule, hard-to-control processes are occurred, including the formation of oxides, nitrides and carbides, structure changes of transported powders and substrate's material in the contact zone. These imperfections are sufficiently decreasing the coating's quality and restricting their usage area for solving different technology tasks. A special scientist's attracted interest is based on the search of alternative technologies directed to the dramatic reduction of the spraying material particle holding time in the gas-dynamic flow and decreasing the temperature flow field. The most real ways, in these cases, are the methods related with the sufficient velocity rising with the simultaneous reduction of the transported dispersed material temperatures [1]. In the present paper, for applying the protective coatings on the welded aluminum riser pipe sections the supersonic cold gas-dynamic spraying (CGDS) method was used.

1 INTRODUCTION

The CGDS method is based on the effect of strong metallic layer formation by the supersonic (up to 2-3 M) flow influence on the normally situated surface. Under these conditions, the temperature of the transported particles is significantly lower than their melting temperature. The aforesaid method has the following advantages:

- The particles are transported in the "cold" state with the velocities up to 2 M and more;
- Particle heating is provided by the transformation of the kinetic energy to heat in the process of interaction with the obstacle, i.e. directly while the coating formation;
- Possibility to obtain coatings, wholly adequate to the spaying powder composition;
- Possibility to obtain composite coatings with constant and controlled composition along its thickness;
- Absence of thermal influence on the substrate's material.

It is known, that the CGDS operations had been carried out since the middle 1980th. With the investigations of the supersonic flows it is detected that if the specific flow velocity (≈ 2M) it is occurred that there could be not only the flow "rounding" of the obstacle, but also the particles deposition on the surface, normally situated with respect to the flow. With that, the particles temperature wasn't more than 100 ^{0}C. The analysis of this effect have provided to the CGDS equipment creation, on which the mechanism of particles bonding on the surface with the velocities 400-1200 m/sec was investigated, and also their deformation rate was estimated. It was mentioned that in the range of the investigated velocities the particles deformation vs. velocity and size dependence was quite weak, so by that case, the mean value of the deformation rate was taken into account. However, under the same velocity values with the particle size increased, the insufficient lowering of the deformation rate is occurred. It also mentioned that the particles of the smaller size had the greater dynamic hardness.

The carried out with the microscope investigation of the surface with the bonded particles showed that the particles initially bonding as cluster-like around which the continuous coating is formatted. This appears, most probably, by the greater activity of the activated boarder areas. Thereby, the cluster is presented as a nucleus of the formatting coating. [1, 2]

Many investigations, on the initial stage, were carried out in the helium environment or in the gas mixture (air-helium). With the growth of helium concentration in the air environment from 0 to 100 % the two-phase flow velocity was increased from 250 to 1200 m/sec. But the usage of helium as a transporting gas denies the possibility of practical applying the CGDS method due to the high value of gas. Thereby the more perspective way to accelerate the particles with the preliminary gas flow (air) heating was investigated.

2 EXPERIMENT

To create the protective coatings with the CGDS the following powder compositions were chosen:

- Coating 1001: Aluminum (40±5) %, alumina (60±5) %;
- Coating 2002: Aluminum (60±5) %; alumina (40±5) %.

Figure 1 shows the scheme of the supersonic cold gas-dynamic spraying equipment.

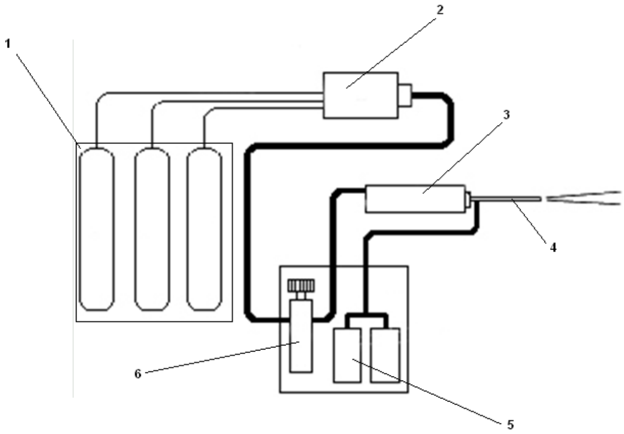


Fig. 1 CGDS equipment scheme (1 – working gas receiver, 2 – working gas purification system, 3 – heater chamber, 4 – Lavalle nozzle, 5 – feeding system, 6 – air discharge regulator).

The CGDS method can be described the following way: the compressed air after the purification system through the pressure regulator moves to the heater chamber, where it heating up to the working temperature and moves to the supersonic nozzle. On the supersonic nozzle edge the high velocity stream of the hot air and powder mixture is formatting. Thereby, a mixture-of-metallic-and-ceramic-particles-like powder having a high kinetic energy comes to interaction with the metal substrate. In the moment of interaction, the complex dynamic processes are occurred in which the metallic particle (the basis of the future coating) is close to the ceramic particle of high energy acting as an indenter and also close to the high velocity reactive stream of the gas carrier. The interaction conditions of these constituents are defining the bonding mechanism of the metallic particle on the substrate, the level of adhesion and cohesion bonding strength, and the conditions of the coating's building up along its thickness [3].

2.1 Electrochemical potentials measurement

For measuring the stationary potential two coating compositions 1001 and 2001 were used.
The stationary potential measurement of the coating samples 1001, 2001 and the riser pipe fragment were carried out on the potentiometer complex with the Cl-Ag reference electrode in the electrochemical cell under normal atmosphere pressure and temperature of 25 ^{0}C. The drilling agent was used as an electrolyte and artificial sea water of the following composition (g/l): NaCl – 26,518; $MgCl_2$ – 2,447; $MgCO_4$-3,305; $CaCl_2$ – 1,141; KCl-0,45; $NaNCO_3$ - 0,202; NaBr - 0,083, pH=6. The

results of the stationary potential measurements are presented on the figure 2 (potential values are recalculated due to normal hydrogen electrode).

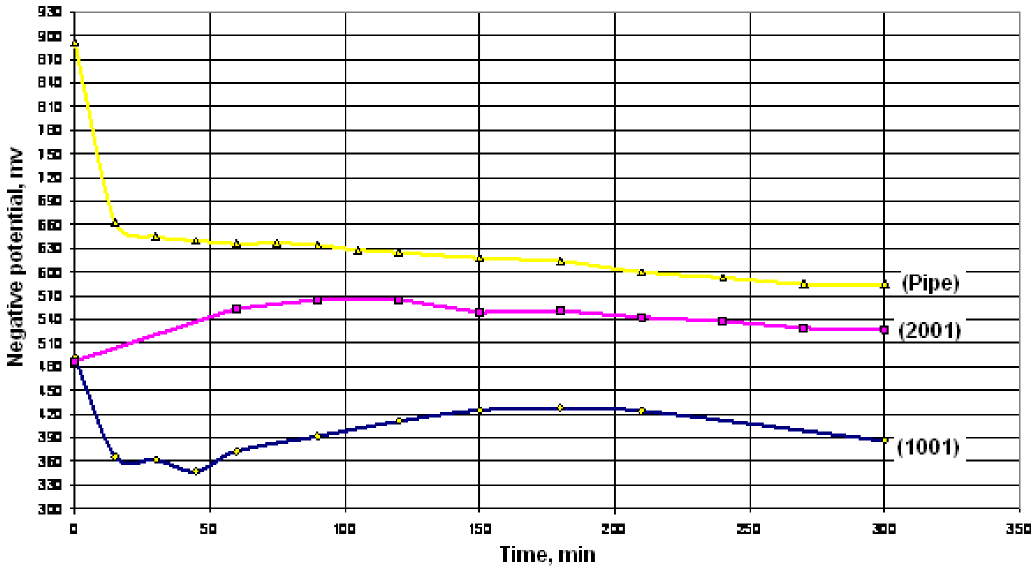


Fig. 2 Negative potential vs. time dependence

Due to the data presented on figure 2, the highest protective properties in the drilling agent are provided by the coating 1001.

2.2. 1001 coating's adhesion strength measurement.
The coupling between the coating and the basis (substrate) is the most important coating's characteristic. The coupling strength of coating and substrate, native and grain boundary strength, cohesion strength of the separate layers are related to the indexes that determines the most part of working characteristics of the coated items. To carry out the adhesion strength tests, the tensile-testing machine (designated for the wire, metal band and thin sheets tensile tests) was chosen. The results of tensile experiments are presented on figure 3.

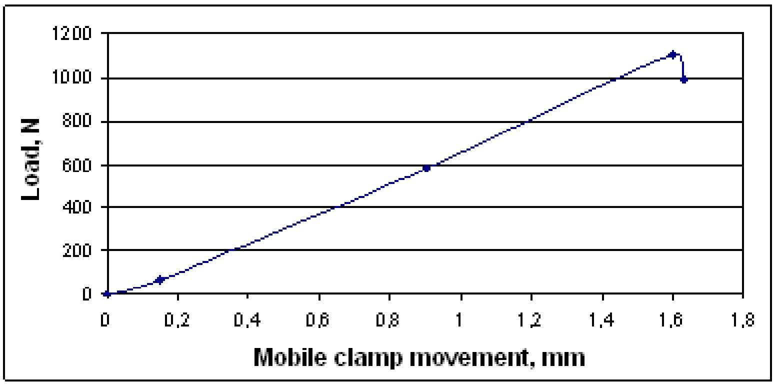


Fig.3 Adhesion strength test results of 1001 coating.

Coating's coupling with aluminum substrate strength was also investigated with the bending tests. The plate specimens (200x30 mm) with different aluminum coating thickness were tested with 3-point bending till the destructive crack is occurred in the coating. The carried out tests showed that the destruction of the coating samples of the 1, 2, 3 mm thickness occurred with the load of 400, 420 and 460 N respectively.

3 PROTECTIVE COATINGS SPRAYING ON THE WELDED RISER PIPE SECTIONS

Incoming inspection of the given riser pipe sections for the further coatings spraying showed that the outer surface of the welded connection had many defects of different nature: metallurgical or due to some mechanical damages (see figure 6 A,B).

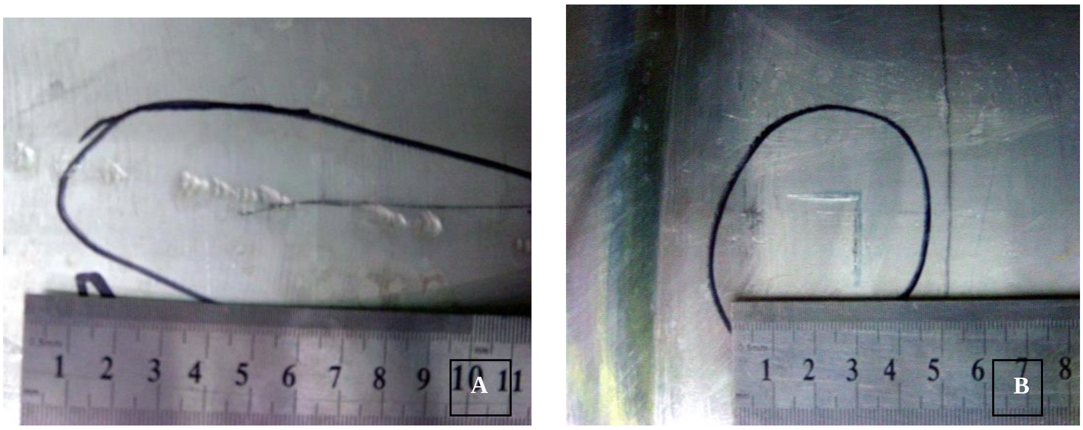


Fig. 4 Defects due to mechanical damages – pinchers (A) and dints (B) on the outer surface of the riser pipe.

The type A defects are insufficiently expanded in the process of spraying, thereby the removal of that kind of defect reduced to coating's thickness building-up in the damaged zone. The inner and outer protective coatings obtained by the CGDS method are presented on the figure 5 A,B.

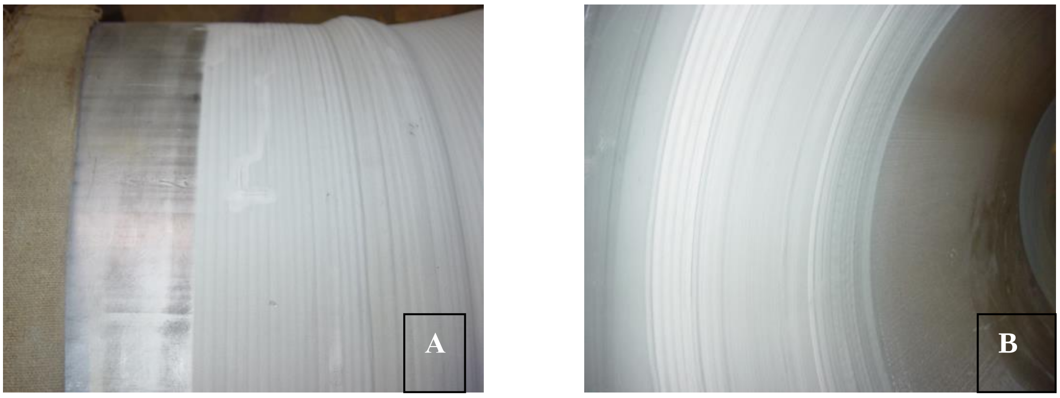


Fig. 4 Outer (A) and inner (B) protective coating 1001

The spraying process influence on the mechanical properties overpatching in the heat-affected zone of the welded connection and beyond it was determined by the metal's microhardness distribution measurements (see figure 5). Usually, beyond the heat-affected zone of the welded connection along the wall thickness of the main riser pipe, the microhardness values distribution is sufficiently solid and corresponds with the level of the mechanical properties of the metal in pressed and thermal treated condition. On the welded connection with the metal coating, the microhardness measurements was carried out from the sprayed layer contact zone deep into the pipe with the 0.5 mm step, though the first measure was done in 100 mcm from the contact zone (see figure 6).

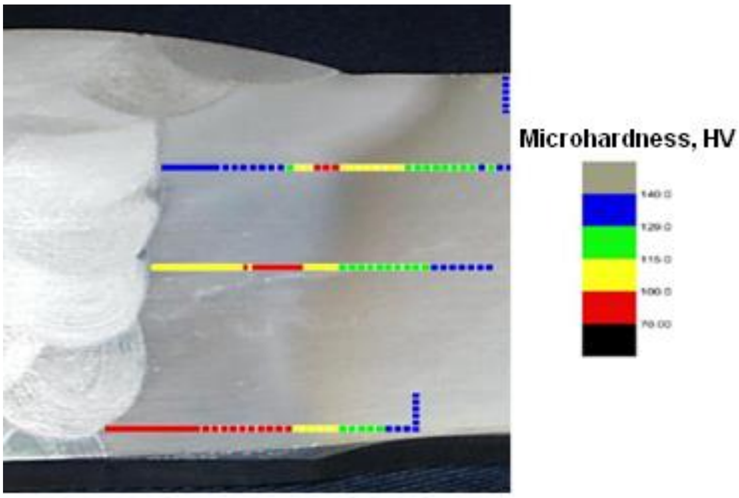


Fig.5 Microhardness distribution on different distance from the welded joint fusion zone

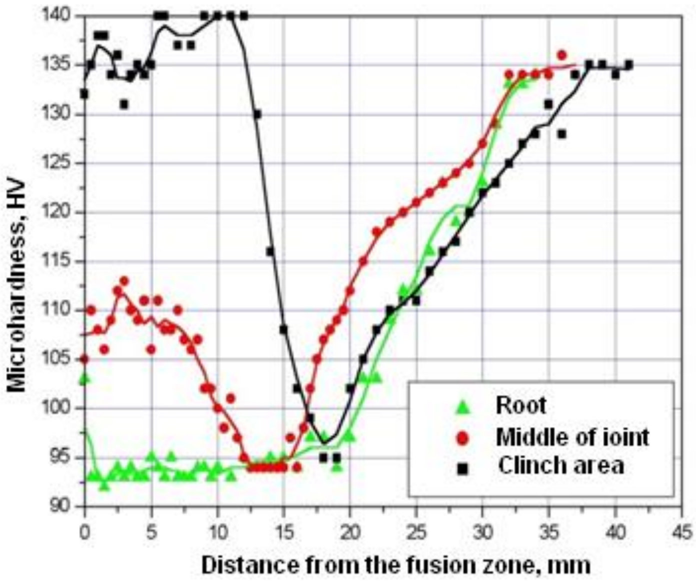


Fig. 6 Microhardness vs. distance from the fusion zone dependence

4 SUMMARY

This paper provides the basic points of the super sonic gold gas-dynamic spraying, its possibility for applying the protective coatings and for repairing the riser pipe sections with the surface defects. It is shown that the best protective properties possessed by the coating 1001. The results of micro hardness measurements on different distances from the fusion zone revealed the influence absence of the spraying process on the micro hardness values of the riser pipe's main metal.

References

[1] Papyrin A.N, Bolotina N.P., Bol' A.A. "New materials and technologies. Theory and practice of material hardening in extreme processes" , Novosibisk: "Nauka", 1992, 200 p.

[2] Klinkov S.V., Kosarev V.F. " Modeling of adhesive interaction of particles with obstacles in gas-dynamic spraying" , "Fisicheskaya Mezomehanika", 2002, P.5 #3, pp. 27-35

[3] Alhimov A.P., Kosarev V.F. Papyrin A.N. "Gas-dynamic spraying. Experimental investigation of spraying process" , PMTF, 1998, P.38 #2, pp. 182-188

Aspects of Integration between DFMA Approaches and PDM Data

Harri Eskelinen[1]

[1]Lappeenranta University of
School of Technology
Mechanical Engineering
Lappeenranta, FINLAND
Email: harri.eskelinen@lut.fi

Abstract

This paper analyzes how the different aspects of design and manufacturing and assembly are included in the overall product lifecycle management model and what the appropriate content of product data management information is to support this overall model. The principles of design and manufacturing and assembly are discussed both to design manufacturing friendly products and to develop product friendly manufacturing processes. In both cases the results are integrated with the relevant product data management data.

1 BACKGROUND

There are several definitions for Product Data Management (PDM), and especially the content of PDM is described in different ways depending on the selected viewpoint. Probably the widest way to understand the content of PDM starts from global business-oriented design, where PDM is regarded as one of the available business functions to support Product Lifecycle Management (PLM).

The narrowest viewpoint presents PDM only as a part of software engineering, where PDM is typically known as the local version control of the product documents. There are other definitions, which mostly fall between these two extreme viewpoints. However, the most common approach is to talk about managing data or information. The main questions are what the type and the content of information needed at different stages of the lifecycle of the product are and how it is ensured that the data is actually available from the IT system at the right time and at the right place.

The modern way to understand PDM systems tries to combine these two viewpoints. Firstly, the use of a PDM system makes it possible to track the different and most relevant costs caused during the design, launch, possible changes and use of a product. Secondly, powerful computer assisted tools and different types of PDM software are utilized to handle different types of information and data collected during the lifetime of the product. The modern viewpoint combines different tools to form an overall PLM model of the market situation, required resources, aspects of industrial production and detailed design aspects of the product.

2 INTRODUCTION

The overall PLM model may focus too closely on such areas as business management systems, handling of administrative data, updating of customer lists, collecting lists of retail distributors and vendors, updating e-catalogs, supplier relationship management and e-procurement, sales order processing, inventory, invoicing, business forecasts, booking and sales analysis. This would lead to a situation where the system is mainly used to maintain product information across multiple business units, such as sales, marketing, procurement and e-business. One risk is that we might create only a one-sided platform that integrates product design data merely with the business processes of the product lifecycle. Another risk is that the PLM system is developed towards a framework with different forms of document templates, which makes it possible to freely share and convey all types of heterogeneous data related to the product. However, although the business-oriented viewpoint and the possibility to convey all possible file formats are important features of an effective PLM system, the key role should be given to the PDM model and more specifically to the aspects of Designing for Manufacturability and Assembly (DFMA). Therefore, the main goal of this paper is to analyze how the different aspects of DFMA are included in the overall PLM model and what the appropriate content of PDM information is to support this overall model (see Figure 1A). Product data can be roughly divided into three main interactive categories, which are technical, administrative and business data, as illustrated in Figure 1B. The main focus in this paper is on technical product data.

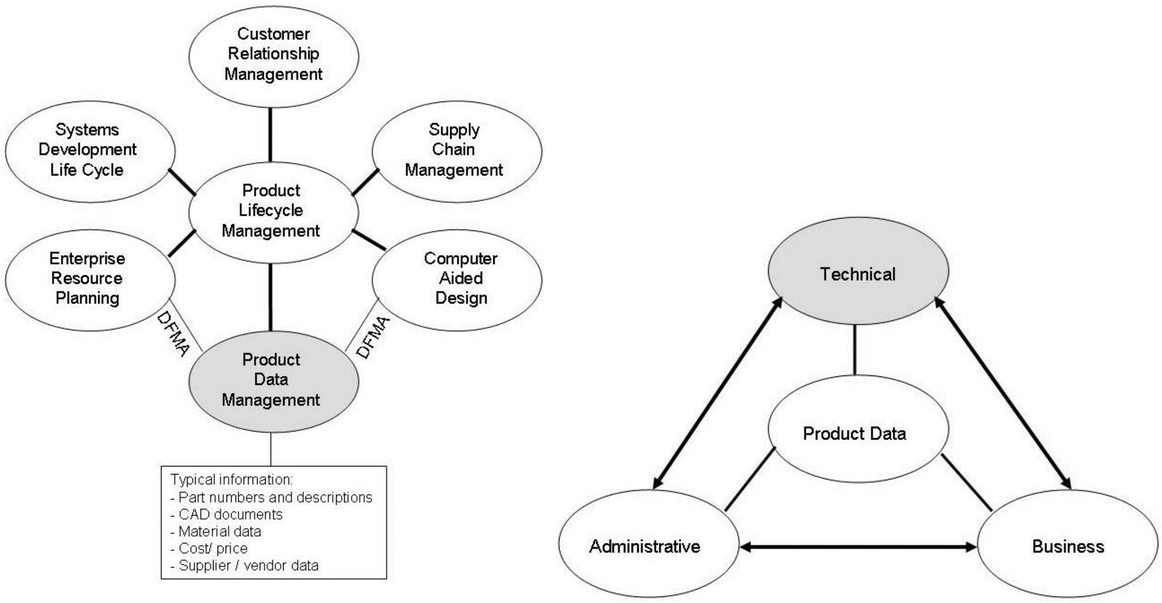


Figure 1. A) Integration between the PLM system and DFMA approaches (right). B) Categories of product data (left).

3 INTEGRATION OF DFMA AND PDM VIEWPOINTS

It is challenging to try to distinguish the part of DFMA data from the product data in the PLM model which is connected only to technical aspects. The technical data is, to a certain extent, always connected with both business and administrative data. However, in this paper, based on [1], the following nine different viewpoints of DFMA will be discussed in relation to relevant technical PDM data:

1. Applied DFMA rules and guidelines for different manufacturing technologies in PDM systems
2. Integration of DFMA evaluation forms and production time calculation techniques with PDM
3. Utilization of modularization, standardization and platforms for PDM
4. Development of advanced manufacturing processes and PDM
5. Determining the most suitable manufacturing technology
6. Utilization of feature-based systems
7. Integrated approaches for controlling and managing both the design and assembly processes and their costs
8. How to handle the development of material science and new material alternatives
9. Utilization of feedback from maintenance.

The starting point of the integration is illustrated in Figures 2A and 2B. We can either divide the product design traditionally into design and production stages (Figure 2A) or we can take a modern approach in which DFMA only aims to find either products easy to manufacture or product friendly manufacturing technologies (Figure 2B). In both cases, the result is the same from the viewpoint of PDM data. Both design and manufacturing data should be included in the technical product data and the system should be able to handle several product versions. Further on, this data is conveyed in both cases to the PLM system.

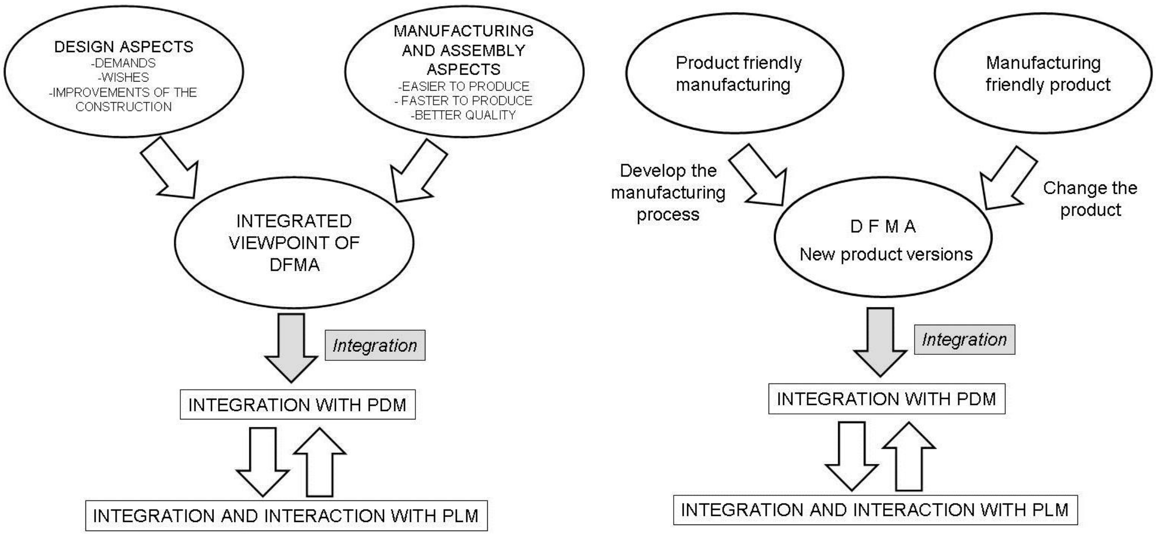


Figure 2. A) The traditional approach utilized in this paper to integrate DFMA and PDM viewpoints (right). B) The principles of DFMA can be utilized either to produce manufacturing friendly products or product friendly manufacturing processes. In both cases, the results are integrated with the PDM data (left).

3.1 About the Utilization of Computer-Aided Means in PDM and PLM systems

Today's requirements entail that several technologies should be integrated into the same product design (e.g. electrical and mechanical design). For instance in the electronics industry, miniature electric components and relatively large (compared with the electric components) mechanical components are included in the same construction. It is possible to utilize virtual prototyping and manufacturing for designing e.g. both electrical circuits and necessary mechanical constructions, their environmental conditions, and suitable manufacturing processes. In these types of cases, simulation is much less expensive and much more comprehensive than testing physical prototypes. Virtual prototyping and manufacturing can also help to detect and correct design and manufacturing problems more thoroughly than physical prototypes through highly accurate numerical analysis and an integrated design system [1]. From the viewpoint of PDM and PLM systems, this means that it should be possible to utilize these tools also virtually to compare different kinds of products and their manufacturing processes without prototyping.

As presented in [1], there are a number of classic tips for the effective use of computer-aided means for DFMA. These tips are also suitable for the effective utilization of PDM and PLM systems. It is necessary in practical work to avoid the modeling of the same geometry repeatedly during the process. This means that it must be possible to fully integrate all of the software packages used in the process. That is the reason for favoring modular software applications in which sketching, drafting, design, finite element analysis (FEA), and simulation of the manufacturing process are linked together. All of the data produced during the process should be saved in a local database which forms the basis for the further development of more general databases, expert systems and artificial intelligence systems. The PDM database contains all data for parts, products, semi-finished products, raw materials, auxiliary structures, supplies, production resources and available tools. Without the database, also the PLM system is paralyzed. On the other hand, by combining the data from the databases, the designer can formulate standard-based and/or modular constructions starting from a sketch in the very early stages of the design process. These databases should be compatible with the ones of all suppliers and customers. The use of standardized and modular constructions creates an important starting point also for computer-aided design. It is easy to add feature-based information into the data of standard components, parts, sub-assemblies or the entire construction to be used for the design of manufacturing or process planning [1]. An effective PDM process needs valid and updated databases of standard-based and modular constructions and components.

To make the early steps of the design more effective, either parametrical modeling or rule-based design systems can be used. Of course, the appropriate use of blocks (either made by the designer or possibly ready-to-use blocks) and layers will improve the efficiency of the actual work with the computer [1]. Both of these features can be embedded in PDM software. Both local and global network solutions are needed. At present, Internet applications have become common in different areas. The basic problem in the use of networking for engineering design is the question of data transfer security [1]. It currently seems that more time is used to demonstrate new ways to integrate different applications of network-based PLM systems than to develop their real content and functional features.

The most effective way to shorten the time needed to complete the product documents for manufacturing is the use of feature-based systems: form features (for example, not just the sphere but the sphere of a ball bearing), geometric features (for example, not just the dimensions of a bored hole but also the direction of the cylinder) or technological features (for example, data on materials or tolerances). The model of the product can also contain information in the form of manufacturing objects (in the data-added sub-programs for manufacturing a specific geometry) or wizards (the software suggests the possible manufacturing methods and the user chooses the appropriate one) [1]. Sometimes it is forgotten that these types of feature-based applications probably started the quick development of PDM and PLM systems. However, the main question might also be: What is the sufficient amount of PDM data which should be included in the feature-based data?

3.2 Aspects of Concurrent Engineering Design

Through the history of DFMA, one powerful tool to support DFMA approaches has been so-called concurrent engineering. It can be regarded also as the root of developing PLM systems. Concurrent engineering design (CE design) is a term that formally describes a set of technical, business, manufacturing planning, and design processes that are concurrently performed by elements of the manufacturing organization. The CE design process, in its simplest form, is the integrated execution of four business and technical processes at the same time. These processes are process management, design, manufacturability and automated infrastructure support [1]. Basically, these processes also belong to the PLM environment. However, in PLM systems the working environment is fully computer assisted but simultaneous processing is not necessary. Instead, the most important aspect is the functional integration of the four main processes.

3.3 Applied DFMA Rules and Guidelines for Different Manufacturing Technologies in PDM Systems

The PDM data of a product could include e.g. some detailed geometries for sheet metal cutting or bending which are based on the traditional DFMA rules of that manufacturing technology. These kinds of rules are, to some extent, connected to the material database of the CAD software, and if the database of the software is updated, the designer is fully able to utilize this feature. Same types of rules can easily be embedded also for casting and different machining processes. The problem might be how to convey this PDM data directly to the production machine without any manual programming or set-up work. However, we should never forget that it is necessary to emphasize the functional aspects of the product, not the manufacturability. Therefore, the PDM data should include more information about the quality and performance aspects (e.g. tolerances, surface properties, ratios describing the relationships between manufacturing accuracy and product performance) of the product than scattered manufacturing data.

3.4 Integration of DFMA Evaluation Forms and Production Time Calculation Techniques with PDM

Even today, there are a number of different sheets or forms available for evaluating the assembly considerations to promote the easy assembly of components. The construction is divided into sub-assemblies and the assembly time for each individual component and sub-assembly is measured. The total assembly time is then calculated and the critical functional components are identified. The improved construction is then formulated by attempting to minimize the number of non-critical components. There are also many types of check-lists which can be used to find out what components are the most difficult for assembly [1]. If the construction and the components are known, this type of data should be included directly in the PDM data of the unit (component, sub-assembly, construction).

Some principles of categorizing the members of a product family based on their performance levels are presented in [2]. Three example cases of permanent magnet machines are introduced. They are used to categorize different wind generator designs by initial parameters such as the rotational speed, outer diameter, length, or diameter of the main rotor, which are given by a customer or another party. Since the generator can be categorized, some of its typical features can be taken into consideration in the early design phase, and further, the manufacturing process can be planned in more detail in the early design phase, as well. This opens up great opportunities for effective design for manufacturing and assembly (DFMA) and integration with the PDM environment.

3.5 Utilization of Modularization, Standardization and Platforms for PDM

The meaning of PDM software is that engineers can use the developed classification system of the components to choose similar parts (find repeated parts) to avoid building, producing, and ordering parts redundantly. However, it is asked quite often what the connection or relationship is between reasonable modularization and standardization and how they affect DFMA and PDM efficiency. In a traditional supply chain model, suppliers send individual parts for an element, such as different sub-assemblies in the automobile industry, to the manufacturer. The manufacturer then assembles the individual parts into that sub-assembly as the car is assembled. In a modular supply chain, the supplier creates the complete sub-assembly and sends it ready to install [1]. One cornerstone of an effective PDM or PLM based project is the appropriate use of modular designs from the PDM database. It is also important for PDM development to continuously add new modular elements into the design database. These modular elements can be either components, interface properties of components and constructions or repetitive manufacturing stages (e.g. a weld seam).

An interesting discussion about the aspects of modularity and standardization is presented in [3]. The article combines these two points of view and produces an Excel-based tool which enables the evaluation and comparison of alternative constructions considering modularity, standardization, manufacturability and the assembly-friendly properties of a product. The generalized idea is presented in Figure 3. The connection to the PDM environment is clear: geometric similarities, similar manufacturing stages or similar interfaces are searched for.

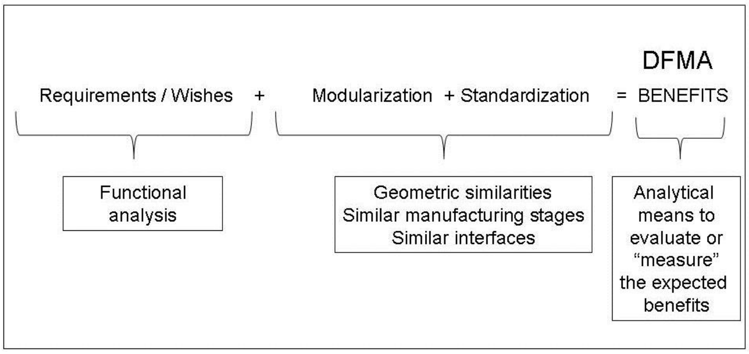


Figure 3. Generalized idea to obtain profit from modularization and standardization from the viewpoint of DFMA [1].

Platform approaches, which are common in the automobile industry, can be classified under this sub-heading because they mainly utilize several types of modular and standardized assemblies. Of course, the platform itself should be regarded as the definitive modular construction.

3.6 Development of Advanced Manufacturing Processes and PDM

According to the traditional way of thinking, slight changes to the product might make the manufacturing phases easier. The contrary approach is that e.g. an entire part of the welding process could be developed to enable product geometries or material combinations which earlier have been difficult or impossible. One example could be hybrid laser GMAW welding, which is an automated, high performance welding process. It results in a very narrow heat-affected zone (HAZ) with deep penetration and high travel speeds relative to traditional processes. This breakthrough approach combines the highly focused intensity of a laser with the joint filling capability of the traditional MIG process. By combining the two, hybrid laser welding provides a unique opportunity for thicker welds with less filler metal or higher travel speeds than typical welding, depending on the material thickness [1]. It is difficult to see how either the PDM or PLM environment alone could lead to this type of development of advanced manufacturing processes. On the contrary, it is highly probable that if the PDM databases dealing with the process parameters and process features are not updated frequently, the product design is forced to apply old-fashioned manufacturing technologies. The recent research conducted on performance, potential and problems of thick section butt joint laser welding of low alloyed structural steels is reviewed in [4]. The article gives a justification for the frequent need to update the PDM databases dealing with material properties, process parameters and available manufacturing processes.

3.7 Determining the Most Suitable Manufacturing Technology

It has been said that the most suitable manufacturing technology for the product should be chosen during the very first design stages of the product to avoid additional costs and to speed up the production and product delivery to the market. Even some mathematical models have been presented for this purpose in [1]. Basically, PDM and PLM systems do not work directly towards this goal. They can give information about how to construct a sub-assembly of the existing components from the design database or how to utilize existing feature-based manufacturing modules, but so far, they have not been able to determine the optimum manufacturing technology. However, within a given technical area, e.g. in sheet metal work, the interactive PDM systems are able to suggest the most suitable geometries or dimensions for easy manufacturing or for manufacturing without sub-contractors.

3.8 Utilization of Feature-Based Systems

The utilization of computer-aided tools to support both DFMA and PDM is one of the most important research areas in the field. Two main viewpoints can be distinguished: Firstly, different types of so-called wizards are used to facilitate design work and to ensure that different DFMA aspects are taken into account during the very first design steps of the product. One typical example is presented in Figure 4 on sheet metal work. In this case, the right shape of the bending corner is added to the model on the basis of the rule-based software application.

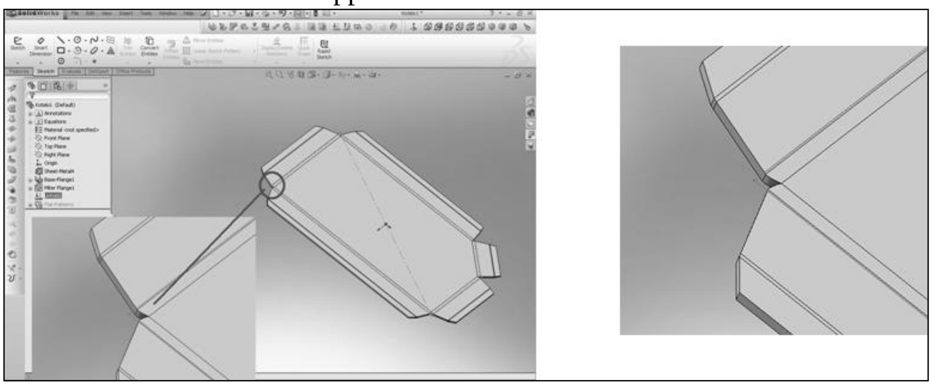


Figure 4. Utilization of wizards in sheet metal component design [1].

Secondly, the integration between different computer-aided areas around PLM is in a key role when striving to improve productivity in global industry. The integration between different computer-aided areas was presented in Figure 1. Especially PDM data is important when the focus is on flexible DFMA in production.

3.9 Integrated Approaches for Controlling and Managing Both the Design and Assembly Processes and Their Costs

Several computer-aided software applications are available which enable evaluating and calculating the assembly times of different alternative sub-assemblies or assemblies. This makes it cost-effective to design a new construction, and at the same time, it is possible to estimate the expected production time and optimize the use of machines and assembly capacity in the workshop [1]. This type of data is easy to utilize and integrate into the DFMA approaches.

3.10 How to Handle the Development of Material Science and New Material Alternatives?

The development of new materials has greatly affected the development of advanced manufacturing and production technologies. Further, this has affected the development of new DFMA applications for the new materials. Especially nanomaterials in general, adaptive materials, nanocomposites and nanoceramics have led to a new generation of DFMA applications [1]. The main difference between the traditional DFMA and DFMA for nanoapplications is the need for utilizing chemistry during the manufacturing processes, which must be taken into account when developing the DFMA approaches. This aspect sets a huge challenge for the development of PDM and PLM systems because completely new features should be created e.g. for PDM databases.

3.11 Utilization of Feedback from Maintenance

An important part of design information for PLM is based on feedback from the service maintenance of the product. The challenge comes from the utilization problems of this information in a global networking environment. However, PLM systems include ready-made features to collect feedback from customers, but the main problem is probably filtering the relevant data to the right persons in the organization. The framework for this viewpoint is illustrated in Figure 5.

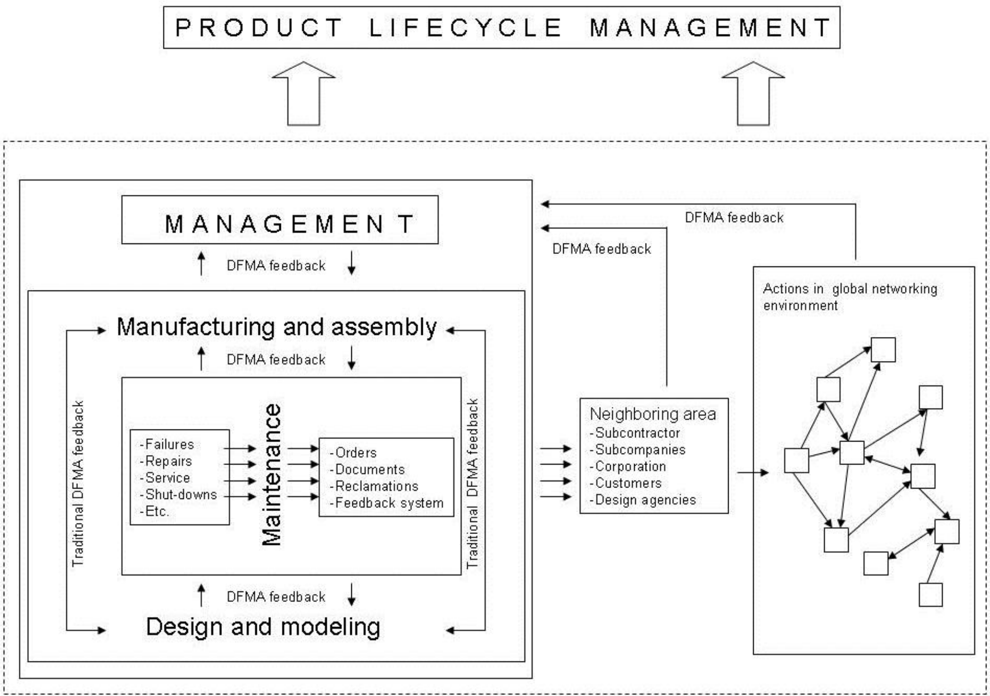


Figure 5. Framework for the utilization of service and maintenance data to improve DFMA approaches in a global networking environment [adapted from 1].

In [5], DFMA is discussed from the viewpoint of maintenance. The article examines the options to utilize networking models, RACI matrices and data flow analyses in networks to fill the communicational gap between designers, maintenance service providers, and end-users. The basic tools for this analysis are presented in Figure 6.

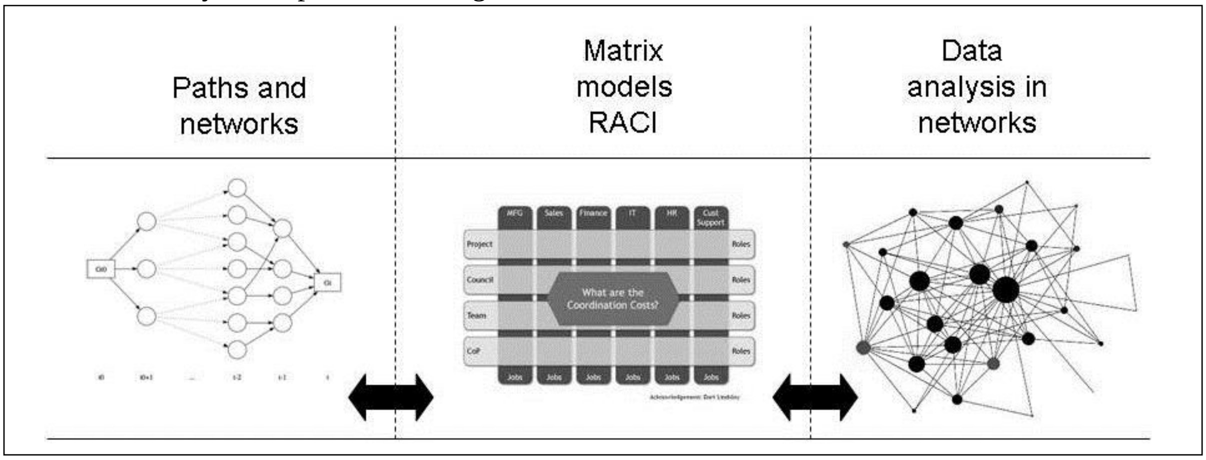


Figure 6. Tools for integrating DFMA and maintenance aspects: path and network models, RACI matrices and data analysis in networks. Notice the interaction between the tools [1].

The potential benefits of this novel approach include the following aspects: the optimization of the manufacturing process by enhancing the features needed by the end-users, reducing manufacturing and maintenance costs in general and reducing the amount of time needed for the decision-making process when new equipment has been installed and commissioned or when already running equipment is unreliable. These three benefits match well with the general advantages which are desired by the use of PLM systems, such as tracking and managing all changes to product related data, a quick return on investment, less time spent organizing design data, improving the overall productivity and improving collaboration between different players.

4 SUMMARY

Based on the discussion presented in this paper, an effective PDM module of a PLM system should fulfill certain requirements. Firstly, the PDM module bridges the gap between design and manufacturing with a controlled and standardized way to manage both prototype design and changes of an existing product. Secondly, although the viewpoint of DFMA emphasizes the technical product data in the PDM module and the PLM system, it is necessary to remember the business-oriented aspects at least for one specific reason: the product development will be carried out based on different types of requirements when the product design task is order-independent and when the task is order-related. In addition to these aspects, the PDM module should include the database of assemblies, which allows to store, search, manage and utilize thousands of discrete parts of various constructions effectively. It is also necessary that the PDM module includes a material database with sufficient manufacturablity data. This means that PDM is a tool which is used from the initial design to the production phase to manage and control all relevant product data. The manufacturing instructions are in a key role. Finally, the main purpose of utilizing PDM modules should be to manage product and production data and share design information to improve collaboration between engineering and manufacturing. This research has also shown that new manufacturing technologies, innovative material selections, advanced and global networking environments in mechanical engineering design and more sophisticated functional requirements of products create an entity which requires improvements to the classic DFMA approaches and which causes some challenges to the existing PDM and PLM environments. In many cases, systematic, analytical and even numerical tools or means can significantly improve both the efficiency of the DFMA approach and functionality of PDM and PLM systems.

References

[1] Eskelinen H., Advanced Approaches to Analytical and Systematic DFMA Analysis, Acta Universitatis Lappeenrantaensis 509, Lappeenranta 2012, ISSN 1456-4491.

[2] Heikkinen J. and Eskelinen H., Introduction to Typical Features and Classification of Wind Generators of Various Sizes, Advanced Approaches to Analytical and Systematic DFMA Analysis, Edited by Eskelinen H., Acta Universitatis Lappeenrantaensis 509, ISBN 978-952-265-366-6, Lappeenranta 2012, pages A11-A18.

[3] Leminen V., Eskelinen H, Matthews S. and Varis J., Development and utilization of a DFMA-evaluation matrix for comparing the level of modularity and standardization in clamping systems, Advanced Approaches to Analytical and Systematic DFMA Analysis, Edited by Eskelinen H., Acta Universitatis Lappeenrantaensis 509, ISBN 978-952-265-366-6, Lappeenranta 2012, pages A30-A39.

[4] Sokolov M. and Eskelinen H., Design Guidelines for Thick Section Butt Joint Laser Beam Welding of Structural Steels, Advanced Approaches to Analytical and Systematic DFMA Analysis, Edited by Eskelinen H., Acta Universitatis Lappeenrantaensis 509, ISBN 978-952-265-366-6, Lappeenranta 2012, pages A40-A49.

[5] Bruzzo J. and Eskelinen H., Improving the DFMA aspects in designers and service providers by taking advantage of the maintenance data from end-users, Advanced Approaches to Analytical and Systematic DFMA Analysis, Edited by Eskelinen H., Acta Universitatis Lappeenrantaensis 509, ISBN 978-952-265-366-6, Lappeenranta 2012, pages A93-A104.

Considering product related aspects on design and development of production systems

Hasse Nylund, Eeva Järvenpää, and Paul H. Andersson

Department of Production Engineering
Tampere University of Technology
Tampere, FI-33101, Finland

Abstract

In this paper, design and development of production systems is discussed. Production systems are studied from the viewpoints of designing new as well as developing existing production systems. The topics are divided into impacts deriving from product development and business processes as well as main areas of production systems design and development. In this context, the use of production system simulation is discussed both on experimenting on new and existing systems. Lastly, several benefits on experimenting with computed models are pointed out.

1 INTRODUCTION

This paper discusses on product related aspects that have an effect on the design and development activities of production systems. These include influences deriving from product development and business processes. From the viewpoint of product development, the input is what a production system should be able to produce. The business processes, on the other hand, specify the forecasted volume and variation of customer orders i.e. when and how much of products from a production system is required.

The possibilities of Information and Communications Technologies (ICT) offer efficient means for the production system design and development. Different computer aided tools and technologies as well as simulation tools and solutions are used in the design and development processes. Even though there are no commonly used definitions, similarities of the definitions and descriptions can be found from the literature (see, for example: [1-6]):

- An integrated approach for improving product and production related engineering technologies
- Computer-aided tools for designing, planning, and analyzing real production systems and processes
- A collection of new technologies, systems, and methods for the digital modeling of the global product development and realization process

Typical areas of the design and development processes are product development, testing, and optimization; production process development and optimization; plant design and improvement; and operative production planning and control [2]. This paper focuses on the areas of simulation of production systems in the design and development processes. The expected benefits are the reduction of sub optimal solutions towards more efficiently operated production systems.

2 IMPACTS FOR PRODUCTION SYSTEM DESIGN AND DEVELOPMENT

Figure 1 presents a simplified example of aspects from product design and strategic business processes influencing on design and development of production systems. Product related information originates from e.g. product data management (PDM) systems while business processes focus on issues such as customers, markets, and competition. These result in the product portfolio and forecasted volume and variation of customer orders that a production system should be able to produce.

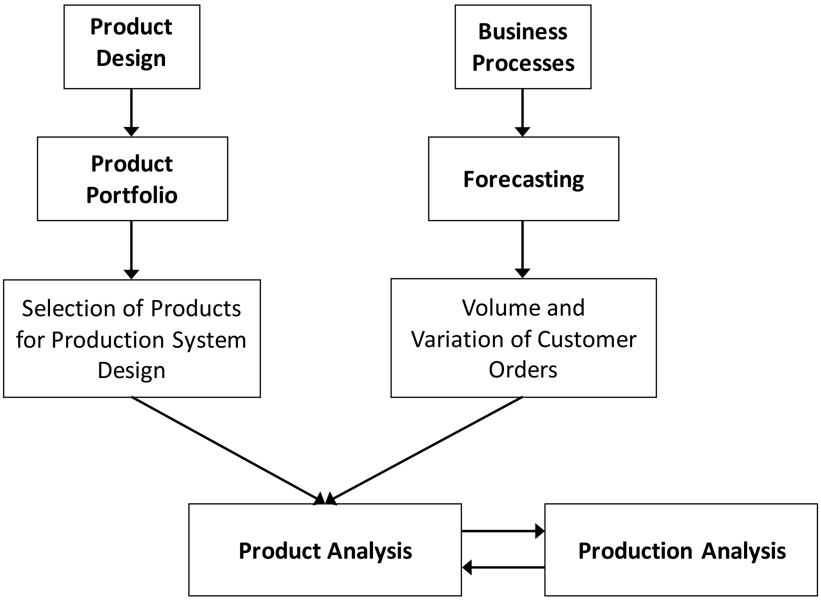


Figure 1. Impacts of product design and business processes for production analysis.

If the product portfolio of a company includes several product families and high number of product variants in the product families, it is typical to reduce the number of products as a base for designing production systems. This can be done by grouping the product variants that are similar from the viewpoint of production i.e. production processes that are required to produce the products. Example criteria for the grouping are:

- *Product size and weight*: Grouping the products by their sizes or weights by classifying them into e.g. small, medium, and large products. This can be used e.g. to select the means of moving the parts at a production facility.
- *Product features*: Manufacturing and assembly features of a product guide and limit the selection of suitable production resources.
- *Material properties*: The selected material of a product impact on selecting feasible parameters for e.g. machining and welding processes.

Product analysis combines the viewpoints of product development and business processes i.e. what and how much should be produced as well as how much variation is forecasted to be both in volume of customer orders and the product mix that forms the volume. Production analysis focuses on what is required from a production system to produce the forecasted volume and variation of products. Example of tool for analyzing production is MPB-analysis (Make, Partnership, Buy). In the MPB-analysis the products are divided into three categories based on e.g. their complexity to be produced and required production methods compared to the core competences of own production system of a company. Products that belong to the category of *Make* are produced by the company itself utilizing the capabilities of the existing machines and devices as well as skills of the workers. In *Partnership*, other companies having the required skills and capabilities are involved. The products falling in this category requires close collaboration between the main company and the partner company, both on product design and designing the required production processes. The alternative *Buy* usually refers to bulk products that are produced and used in high volumes. These are typically ordered from suppliers with no or minimum requirements for collaboration.

3 MAIN AREAS OF PRODUCTION SYSTEM DESIGN

The production analysis serves a base for design and development of production systems. **Figure 2** presents the main areas; system structure, control principles, production technologies, and layout design [7]. Simulation is used to evaluate the decisions on individual production technologies as well as the production flow of the whole production system.

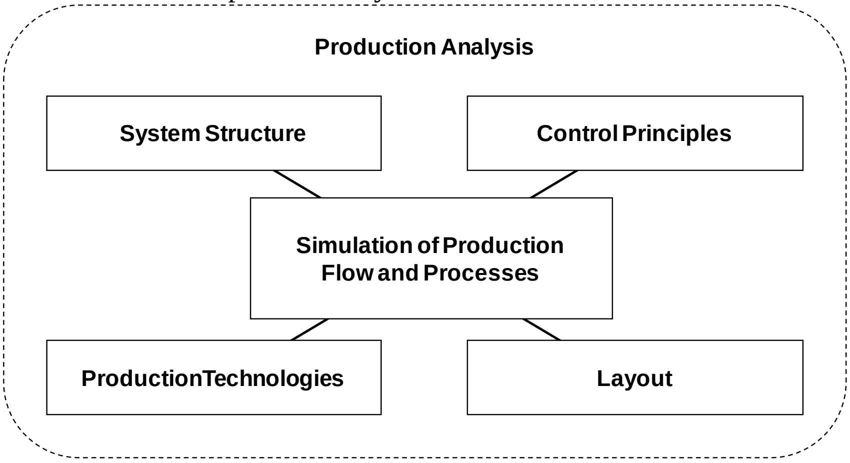


Figure 2. Main areas of designing and evaluating production systems.

System structure defines the facilities used to produce products. They can be divided into blank part and raw material suppliers, part manufacturing units, sub-assembly units, and final assembly units [8]. These units are usually distributed into several different locations forming a supply network for the final products produced in the final assembly units. Production systems can be controlled in different ways with different *control principles* to produce the right products at right times based on the type of products and the strategy of a company. Production control answers to questions of what, when and how much should be produced. Typical examples of control principles are order-based and stock-based controls. In order-based control, production is based on customer order and the products are typically connected to a certain customer already when they are produced. The stock-based control produces product into stocks from where products are collected based on customer orders.

Manufacturing technologies focuses on production processes i.e. the production steps that are needed to produce the products. Typical issues are selection of machines and devices with desired manufacturing methods and means for transferring material in a factory floor. *Layout* explains how the needed manufacturing and storage areas as well as paths for material transferring will be located on a factory floor. Typical layout alternatives are cellular and functional areas as well as stages and lines. Most factories consist of combination of different layout alternatives.

4 SIMULATION SUPPORTED IMPROVEMENT OF PRODUCTION SYSTEMS

Simulation, especially discrete-event simulation (DES), is widely recognized method in different production system design and development processes, but it is applied in a small fraction of cases, i.e. those in which it can bring significant value [9]. DES is used when the model evolves over time. The states of the production entities, i.e. machines, tools, and workers, change at separate points in time. Simple models can be investigated analytically, but typical production systems and the relations between the entities are too complex to solve without simulation. The use of modeling and simulation is one of the largest application areas of the design and development of production systems. Typical areas usually addressed using modeling and simulation is, for example [10-11]:

- Need and the number of resources, both humans and machines, i.e. defining the needed capacity of the system.
- Performance evaluation, such as throughput and bottleneck analysis.

- Evaluation of operational procedures, such as controlling, planning, and scheduling of production activities.

Simulation in the context of this paper is used to represent a real, physical production system with computer models. The purpose is to understand the behavior and characteristics of a real production system and analyze different scenarios when changes are made in one or more of the main areas of production system design.

4.1 Simulation in Designing New Production Systems

System structure involves several facilities in different locations. Simulation can be used to evaluate especially issues concerning logistical issues e.g. deliveries between the locations. Delivery batches can have parameters such as batch size i.e. number of products in a delivery, duration of the batch delivery, and intervals between batches. If these parameters have a mean value and a certain variation, the effect of delivery reliability can be evaluated.

For the control principles, simulation can be used to compare different control alternatives and their effect on the timeliness of the supply network, defined by the system structure. Typical issues include bottleneck analyses to find out the facilities that limit the capacity of the supply network. These facilities can then be used as the control points of the timely flow of material, or points where the most development efforts should be focused on.

In order to be able the produce the changing volume and variation of customer orders, manufacturing technologies play a key role in achieving the wanted results. Manufacturing technologies include resources such as machines, devices, and workers for producing the products and material handling i.e. transferring the products between storages and production units. With simulation, the need for number of different kind of resources as well as need for parallel resources can be estimated. These require that durations of different production activities are known, or estimates of the production times can be achieved if the selection of the manufacturing technologies is not yet done. Examples of production times are processing, setup, load, and unload times as well as durations of e.g. failures and repairs as well as absences of workers.

Layout and layout design define the physical appearance of a production facility. The control principles and manufacturing technologies set the requirements for layout design. The number of required machines and devices, together with the working area they require, impact on the layout design. The production areas should be located along with areas for storing products as well as pathways to transfer the products inside a facility to ensure timely flow of material from blank parts to finished products. The control principles have an impact on the needed space for storing the products. In stock-based control, the control principle itself set the requirements for the size of a storage area while in order-based control the changes in production volumes and variation should be considered. With simulation both the needed area for storing products and evaluation of the material flow can be assessed.

4.2 Simulation in Development of Existing Production Systems

For the development of existing production systems, the situation differs from designing new production systems in that only part of the system may be required to be changed. The main goal is to find a solution for the changed production system that fulfills the requirements of the existing production as well as the production of the new products. The fashion of the simulation experiments of different kind of situations can be divided as follows:

- *Experiments on existing production system*: The new requirements match the capabilities of the existing system i.e. the capabilities exist for all of the product requirements without any need for changes to the physical system. The feasibility of the system can be validated with simulation experiments.

- *Experiments on reconfigured production system*: The production system as its current state cannot fulfill all the requirements. Simulation can be used to experiment if a system can be reconfigured to a new state.
- *Experiments after new implementations into the production system*: The system does not have the needed capability even after reconfiguration. It may be possible if new capabilities can be added to the system. Again, this can be verified with simulation experiments.

The simulation experiments may result in a situation, where the requirements cannot be fulfilled. Similarly, even if a simulation experiment shows that the solution is generally acceptable, it still needs to be evaluated against possible limiting factors, such as maximum cost of the change. In both cases, if the solution alternative doesn't fulfill all the requirements, it should be possible to send feedback to product development to find an alternative solution to be experimented.

4.3 Benefits of Simulation of Production Systems

Simulation is a key technology in an integrated approach to enhancing product and production engineering processes [2]. Typical areas of simulation in the design and development of production systems are, for example [12-13]:

- Experiments on a computer model do not disturb the real production system. New operating policies and procedures can be experimented with and evaluated in advance.
- Solution alternatives can be compared within the system constraints. Possible problems can be identified and diagnosed before actions are taken in the real system.
- Modeling and simulation tools offer real-looking 3D models and animations. Visualization can be used to support decision making and training workers.
- Being involved in the building a simulation model increases individuals' knowledge of the system, its characteristics and behavior.

More specific advantages of simulation on the process deriving from the impact from product development and business processes on design and development of production systems are, for example [14]:

- When new products or product variants are suggested, simulation can be used to evaluate the system's capability to produce the products.
- Different solution alternatives can be compared and the most suitable solution can be selected to be considered for implementation.
- The solution alternatives can be viewed against factors such as cost, quality, and time, as well as how they affect the operation of the existing system.
- Using the approach in the early steps of product development or forecasting customer behavior makes it possible to detect change requirements in advance.

5 SUMMARY

This paper discussed on design and development of production systems. In the process from the impacts of product development and business processes the emphasis of product decreases while the importance of designing and developing production systems increases. This observation strengthens the commonly agreed issue that many of the decisions are made in the early phases of the process having an effect on the phases later in the process. Therefore, allowing feedback from the later parts of the process, resulting changes to the early phases, can lead to more efficient solutions.

Simulation of production systems was discussed on designing new and developing existing production systems. In designing new production systems, the discussion focused on the main areas of production system design. In developing existing production systems, simulation was focused on existing and reconfigured systems as well as systems that need implementation of new resources and methods.

Lastly, several advantages using simulation in the context of production systems were discussed generally and in the context of production i.e. product development and business processes.

6 ACKNOWLEDGEMENTS

The research presented in this paper is co-financed by Tekes, the Finnish Funding Agency for Technology and Innovation, and several major companies in Finland.

References

[1] *Bracht U and Masurat T, The Digital Factory between vision and reality. Computers in Industry, Vol. 56, 2005, pp 325-333*

[2] *Kühn W, "Digital Factory - Integration of simulation enhancing the product and production process towards operative control and optimization", International Journal of Simulation, Vol. 7, No. 7, 2006, pp 27-39*

[3] *Maropoulos PG, Digital enterprise technology-defining perspectives and research priorities, International Journal of Computer Integrated Manufacturing, Vol. 16, Nos. 7-8, 2003, pp 467-478*

[4] *Offodile, O.F., Abdel-Malek, L.L. The virtual manufacturing paradigm: The impact of IT/IS outsourcing on manufacturing strategy. International Journal of Production Economics. 2002. Volume 75. Pp 147-159.*

[5] *Reiter, W.F. Collaborative engineering in the digital enterprise. International Journal of Computer Integrated Manufacturing. 2003. Volume 16, Issue 7-8. Pp 586-589.*

[6] *Souza, M.C.F., Sacco, M., Porto, A.J.V. Virtual manufacturing as a way for the factory of the future. Journal of Intelligent Manufacturing. 2006. Volume 17. Pp 725-735.*

[7] *Lapinleimu, I. Ideal Factory Theory of Factory Planning, Produceability and Ideality. Doctoral Thesis. Tampere University of Technology, Publications 328. 2001. 195p.*

[8] *Lapinleimu, I., Kauppinen, V., Torvinen, S. Kone- ja metalliteollisuuden tuotantojärjestelmät (in Finnish). Tammer-paino. 1997. 398 p.*

[9] *Pegden, C.D. Future directions in simulation modeling. Winter Simulation Conference 2005, Orlando, FL, USA.*

[10] *Law, A.M., Kelton, W.D. Simulation modeling and analysis, 3rd Edition. McGraw-Hill. 2002. 792 p.*

[11] *Law, A.M., McComas, M.G. Simulation of Manufacturing Systems, In: Farrington P.A., Nembhard H.B., Sturrock D.T., Evans G.W. (eds), Proceedings of the 1999 Winter Simulation Conference, Squaw Peak, Phoenix, AZ, pp. 56-59.*

[12] *Banks, J. Introduction to Simulation. In: Joines, J.A., Barton, R.R., Kang, K., Fishwick, P.A. (eds.), Proceedings of the 2000 Winter Simulation Conference. 2000. Pp 9-16.*

[13] *Carson, J.S. Introduction to Modeling and Simulation. In: Kuhl, M.E., Steiger, N.M., Armstrong, F.B., Joines, J.A. (eds.), Proceedings of the 2005 Winter Simulation Conference. 2005. Pp 16-23.*

[14] *Nylund, H., Salminen, K. Andersson, P. H. An approach to the integrated design and development of manufacturing systems. In: Roy, R., Shehab, E. (eds.), Proceedings of the 19th CIRP Design conference, Competitive Design. 2009. Pp. 428-435.*

Data base of materials and technologies of Arctic application

E.A. Yakovleva, E.I. Khlusova, V.Y. Mikhailova

Structural integrity department
FSUE CRISM "Prometey"
Saint-Petersburg, 191015, Russia
VictorM@crism.ru

Abstract
The specialists of FSUE CRISM "Prometey" have developed a database of materials and technologies for polar regions. As part of the work to be completed, they examined 58 steel grades for ships and marine structures, 47 building steel grades produced by the leading makers of rolled metallic products in Russia as per the requirements of 9 standards from 4 to 120 mm in thickness. Database has a control module This system provides information management on the suppliers of metallurgical products in the Russian Federation designed for industrial building, shipbuilding and pipeline transportation operating in the northern regions.

1 INTRODUCTION

The work is fulfilled by FSUE CRISM «Prometey» as part of the Partnership Agreement «Arctic Materials Technologies Development» dtd. 01.02.2012 with the Lappeenranta University of Technology.

Of late years the Arctic exploration has become even more active. Not only the selection of a suitable material but the manufacturer of metallurgical products for Arctic applications is very important since there are hundreds of operating Russian enterprises involved in the production of marine equipment and facilities as well as metallurgical products. The specialists of FSUE CRISM "Prometey" have developed a database of materials and technologies for polar regions regarding the potentialities of producers and plants building different structures in the Russian Federation.

The suggested system assumes not only information storage in the most user-friendly way but information management on the suppliers of metallurgical products in the Russian Federation designed for operation in northern regions. The database summarizes data on shipbuilding and building steel grades for the Arctic region made in Russia, namely, on the range of products, producers, requirements for chemical composition and mechanical properties according to the national standards of the Russian Federation and the regulatory document of IACS (the International Association of Classification Societies). As part of the work to be completed, they examined 58 steel grades for ships and marine structures, 47 building steel grades produced by the leading makers of rolled metallic products in Russia as per the requirements of 9 standards from 4 to 120 mm in thickness.

The database includes shipbuilding steels showing normal, high and higher strength with yield strength up to 690 MPa falling into D, E, F categories. They meet the requirements of GOST 52927, the Russian Maritime Register of Shipping, Germanischer Lloyd, Det Norske Veritas, Bureau Veritas, American Bureau of Shipping, Lloyd's Register. Building steels of cold-resistant grades meet the requirements of GOST 19282-73 and GOST 27772-88. The database is to be added with data on the steels for the main pipelines and then extended with those on rolled profiles and sections.
The leading Russian producers of metal rolled products are the following metallurgical works: OAO «Severstal», Cherepovets, Vologda Region (http://www.severstal.ru), OAO «Magnitogorsk Iron and Steel Works» (MMK), Magnitogorsk, Chelyabinsk Region (http://www.mmk.ru), «OMZ Special

Steels» LLC, Kolpino (http://omz-specialsteel.com/production/listovoy-prokat/sudostroenie/). These metallurgical works manufactures produces shipbuilding steels 4-120 mm in thicknesses according to the requirements of the Russian River Register, the Russian Maritime Register of Shipping, GL, ABS, BV, DNV, LR,

2 DATABASE STRUCTURE

The database interface represents a hypertext HTML-format structure (open for any browser) including a list of steel grades with accessible information on them (Fig. 1).

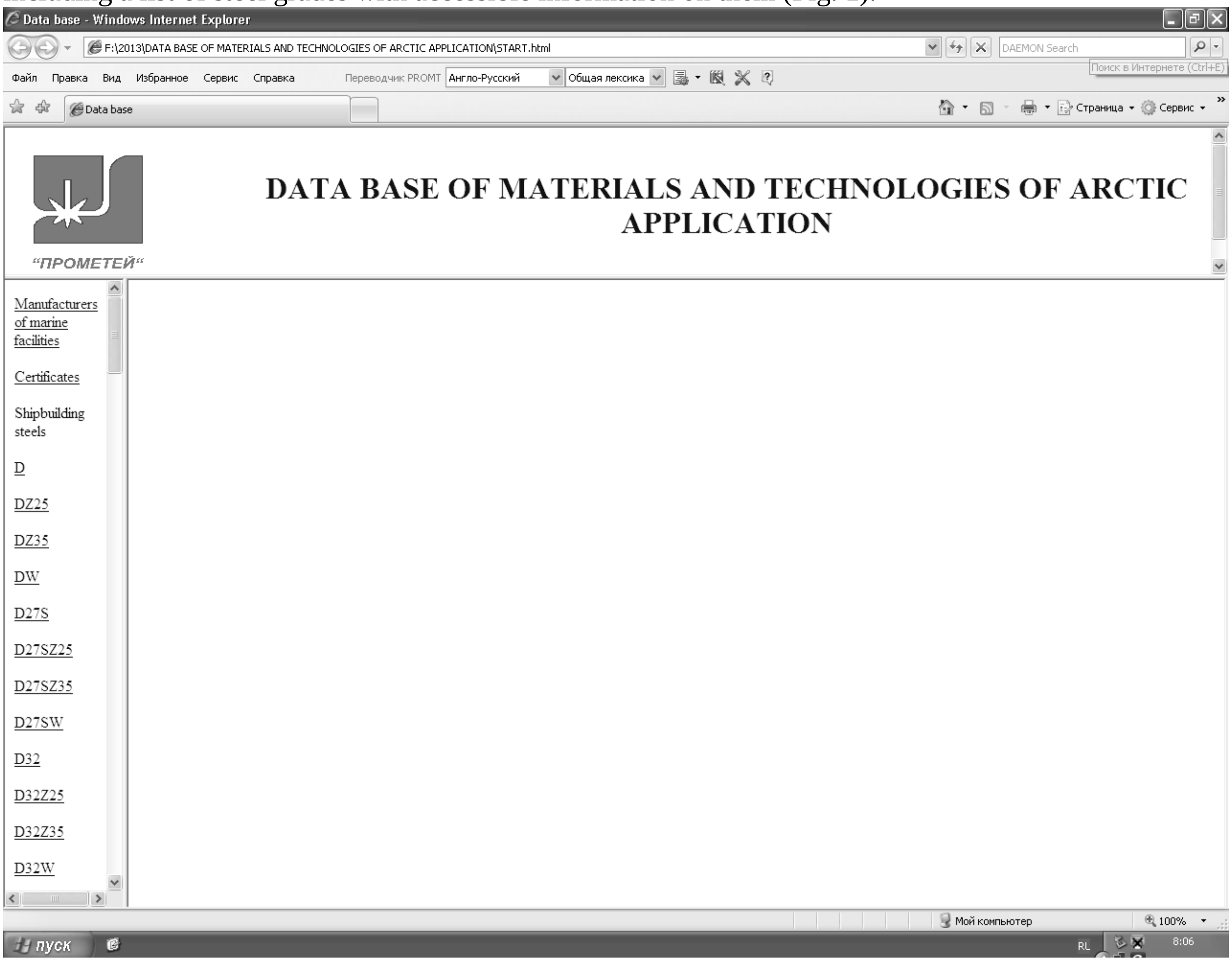
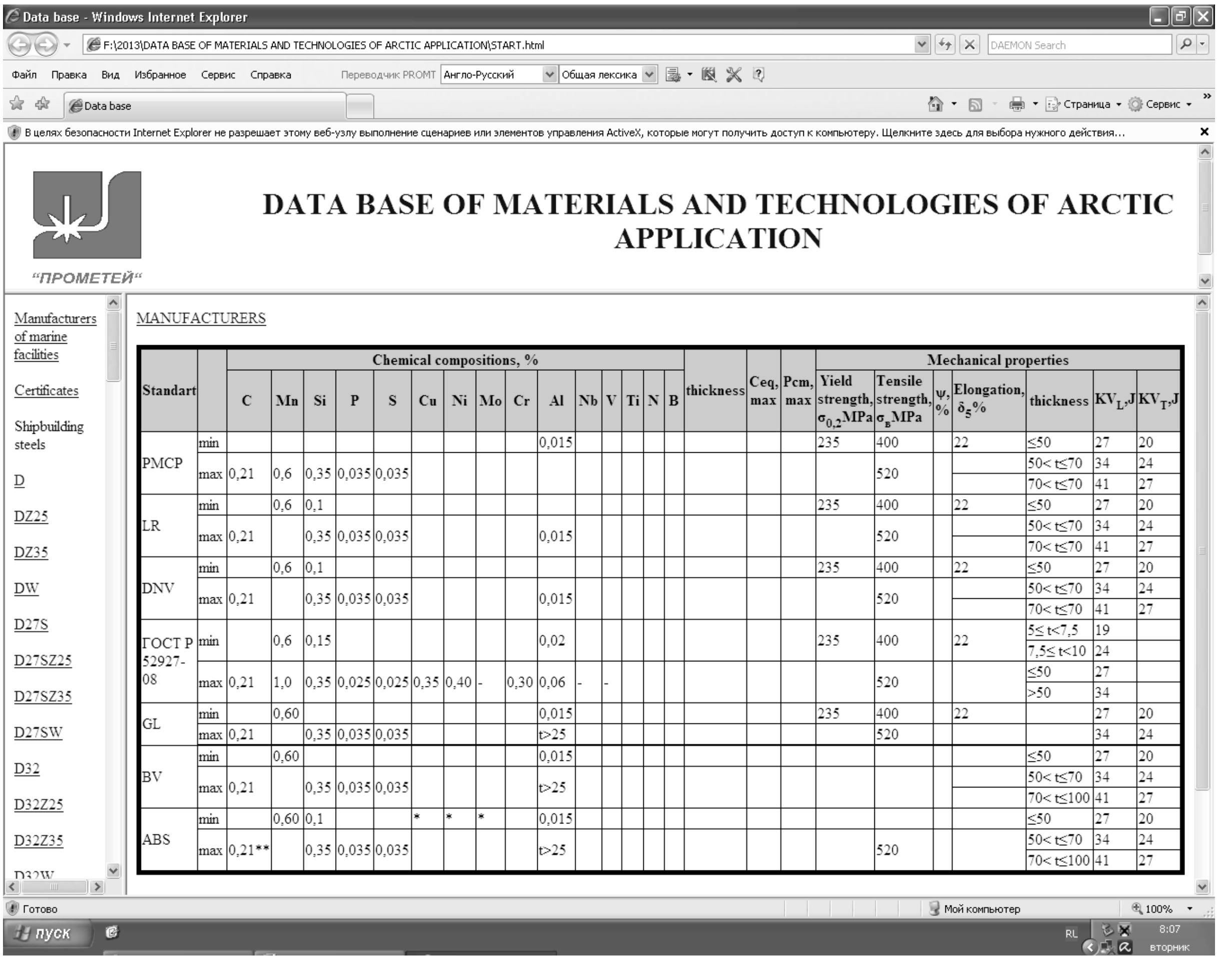


Figure 1 Database interface. List of steel grades.

Clicking the steel grade name opens the table that presents the complete information. All the tables have a typical structure (Fig. 2), namely, they include a list of standards specifying the requirements for relevant information, chemical composition (mass %), carbon equivalent for different thicknesses and mechanical characteristics (yield strength, ultimate strength, elongation, reduction in area, impact energy in longitudinal and transverse directions). There are minimum and maximum values for the above quantities.



Standart		Chemical compositions, %															thickness	Ceq, max	Pcm, max	Mechanical properties							
		C	Mn	Si	P	S	Cu	Ni	Mo	Cr	Al	Nb	V	Ti	N	B				Yield strength, $\sigma_{0,2}$MPa	Tensile strength, $\sigma_в$MPa	ψ, %	Elongation, δ_5%	thickness	KV_L,J	KV_T,J
PMCP	min										0,015									235	400		22	≤50	27	20
	max	0,21	0,6	0,35	0,035	0,035															520			50< t≤70	34	24
																								70< t≤70	41	27
LR	min		0,6	0,1																235	400		22	≤50	27	20
	max	0,21		0,35	0,035	0,035					0,015										520			50< t≤70	34	24
																								70< t≤70	41	27
DNV	min		0,6	0,1																235	400		22	≤50	27	20
	max	0,21		0,35	0,035	0,035					0,015										520			50< t≤70	34	24
																								70< t≤70	41	27
ГОСТ Р 52927-08	min		0,6	0,15							0,02									235	400		22	5≤ t<7,5	19	
																								7,5≤ t<10	24	
	max	0,21	1,0	0,35	0,025	0,025	0,35	0,40	-	0,30	0,06	-	-								520			≤50	27	
																								>50	34	
GL	min		0,60								0,015									235	400		22		27	20
	max	0,21		0,35	0,035	0,035					t>25										520				34	24
BV	min		0,60								0,015													≤50	27	20
	max	0,21		0,35	0,035	0,035					t>25													50< t≤70	34	24
																								70< t≤100	41	27
ABS	min		0,60	0,1			*	*	*		0,015													≤50	27	20
	max	0,21**		0,35	0,035	0,035					t>25										520			50< t≤70	34	24
																								70< t≤100	41	27

Figure 2 Database interface. Shipbuilding steels. Steel grade: category D, chemical composition and mechanical characteristics.

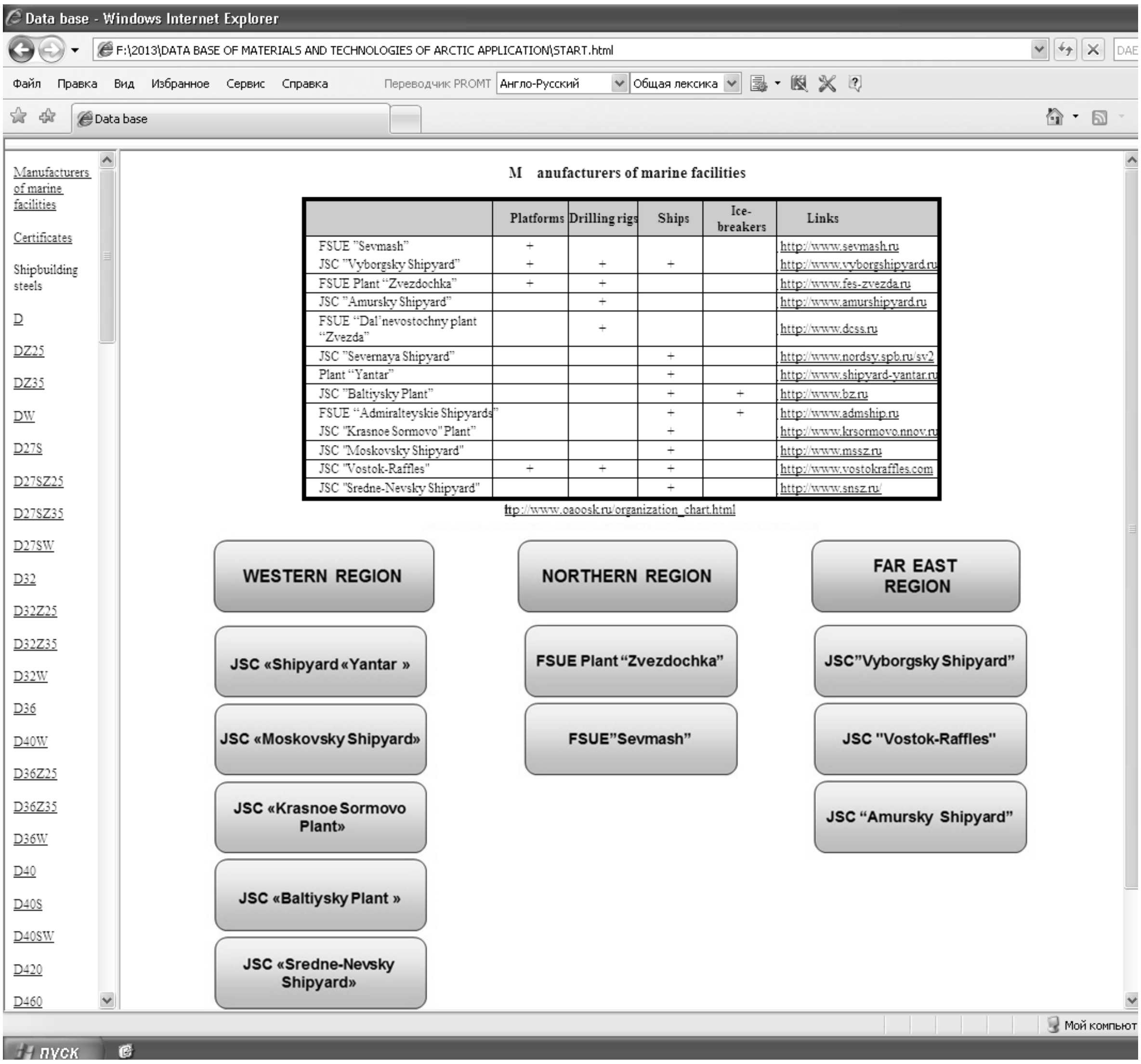
There are also PDF-format applications in the form of valid certificates for the production of shipbuilding materials for the available enterprises. In addition to the database, there is a summarized table about the leading Russian producers of marine structures and equipment (platforms, drilling rigs, ships, ice breakers) as well as their regional distribution (Fig. 3).

Baltiysky Zavod JSC (http://www.bz.ru/) is one of the leading shipyards in Russia. Over 156 years the plant has built more than 600 ships and vessels.

Vyborg Shipyard JSC (http://vyborgshipyard.ru) is one of the largest state-of-the-art shipbuilding companies of the North-Western Region of Russia with over 60-year experience in shipbuilding.

JSC Shipbuilding plant «Severnaya Verf» (http://www.nordsy.spb.ru/) is one of the leading Russian shipbuilding enterprises, it is put on the National List of the Leading Russian Industrial Enterprises.

JSC «Admiralteiskie Verfi» (http://admship.ru/?page_id=8) is among the leading Russian shipbuilding companies. The admiralty wharfs is the state-of-the-art enterprise taking an active part in the development of national shipbuilding.



	Platforms	Drilling rigs	Ships	Ice-breakers	Links
FSUE "Sevmash"	+				http://www.sevmash.ru
JSC "Vyborgsky Shipyard"	+	+	+		http://www.vyborgshipyard.ru
FSUE Plant "Zvezdochka"	+	+			http://www.fes-zvezda.ru
JSC "Amursky Shipyard"		+			http://www.amurshipyard.ru
FSUE "Dal'nevostochny plant "Zvezda"		+			http://www.dcss.ru
JSC "Severnaya Shipyard"			+		http://www.nordsy.spb.ru/sv2
Plant "Yantar"			+		http://www.shipyard-yantar.ru
JSC "Baltiysky Plant"			+	+	http://www.bz.ru
FSUE "Admiralteyskie Shipyards"			+	+	http://www.admship.ru
JSC "Krasnoe Sormovo" Plant"			+		http://www.krsormovo.nnov.ru
JSC "Moskovsky Shipyard"			+		http://www.mssz.ru
JSC "Vostok-Raffles"	+	+	+		http://www.vostokraffles.com
JSC "Sredne-Nevsky Shipyard"			+		http://www.snsz.ru/

Figure 3. Leading producers of marine equipment and structures in Russia.

Besides, the database has a control module This system provides information management on the suppliers of metallurgical products in the Russian Federation designed for industrial building, shipbuilding and pipeline transportation operating in the northern regions. Specifying the steel grade and dimensions, the optimum Russian supplier of relevant metallic products can be selected.

3 CONCLUSION

Thus, possessing information on the promising building of ships or marine structures it is possible to select relevant information on the producer of material for this structure in the best way taking into account the selected range of products, steel grades and production approval certificates.

Electrochemical Wear and Corrosion Resistant Coatings for Arctic

Krasikov A.V[1]., Ezhov A.A.[1]
[1] FSUE CRISM "Promrtey"
St. Petersburg, 195015 Russia

Abstract
A complex research of nickel and tungsten ions electroreduction from pyrophosphate electrolyte was carried out in FSUE CRISM "Prometey" and a probable codeposition mechanism of these metals was shown. Taking into account these data an electrolyte composition and conditions were developed for electroplating of nickel-tungsten coatings with tungsten content up to 30 wt.% and microhardness up to 7.0 GPa. A phase composition and morphology research of coatings obtained by corundum nanoparticles incorporation in oxide coating formed during microarc oxidation was carried out. A method of composite cermet coatings TiO_2*/Ni-W was developed.*

1 INTRODUCTION

In the arctic conditions a wide specter of cold-resistant materials are used: special steels, bronzes, aluminum and titanium alloys. Numerous coatings and their plating methods were suggested for wear and sea corrosion protection. Very perspective for these purposes are electrochemically deposited nickel-tungsten alloy, which has both high hardness and corrosion resistance [1-5], as well as ceramic coatings, being formed on titanium by electrochemical doping of surface under oxidizing (EDSO). Also cermet composite coatings consisting of oxide matrix and corrosion-resistant alloy, for example Ni-W, are perspective materials.

2 EXPERIMENTAL METHODIC

Nickel-tungsten coatings were plated on steel samples of size 15x30x1 mm and oxide coatings were formed on the surface of titanium samples of 18x45x1 mm. The coatings were plated according to technologies, developed in FSUE CRISM "Promrtey", Russia.

The coatings morphology was examined with scaning electrone microscope Tescan Vega 3. Phase composition of the coatings was studied by X-ray diffractometer Bruker D8 Advance. Coatngs chemical composition was determined by energy dispersion method with analyzer Niton Xl3t and microanalyzer Inca X-Max mounted on the electron microscope. Corrosion rate was estimated by mass lost of the sample after exposition in 3% NaCl water solution for 120 hours.

3 GALVANIC NICKEL-TUNGSTEN COATINGS

In spite of its advantages nickel-tungsten alloy has its own disadvantages. The important disadvantage of the alloy is high brittleness, and microcracks are often observed in surface microphotos of nickel-tungsten coating, obtained by various researchers.

Yet, Japanese scientist Thoru Yamasaki has obtained nickel-tungsten coating without cracks [6], which confirms the ductile alloy deposition to be possible. The alloy in T.Yamasaki works was deposited from electrolyte based on citric acid, which is often oxidated on the anodes during electrolyte exploitation and its oxidation products decrease coatings properties. In FSUE CRISM "Prometey" a more stable pyrophosphate electrolyte and conditions were developed for nickel-tungsten alloy deposition.

At the first step of this research a problem of Ni-W alloy brittleness had to be solved. The literature analysis have shown that the reason of crack formation may be natural lattice defects of nickel-tungsten alloy, incorporation into the alloy of hydrogen evolving while electrochemical coating forming and non-metallic impurities presence in the alloy. The first reason is determined by nature of the alloy (which is a nanocrystalline solid solution of tungsten in nickel) and cannot be eliminated, the two others can be theoretically eliminated or their influence can be reduced to minimum. Hydrogen incorporation can be reduced by increasing of electrolyte temperature and alloy current efficiency.

A mechanism of nickel and tungsten codeposition was necessary to be investigated for determination of impurities formation reasons in the alloy and hence to develop measures of their formation prevention. During a complex research of nickel and tungsten ions joint reduction from the pyrophosphate electrolyte the orders of these electrochemical reactions were found. These data allowed to estimate that nickel reduction process goes throw the limiting stage of formation of intermediate particle $NiOH_{ads}$, adsorbed at the cathode, and tungsten reduction goes throw formation of adsorbed intermediate $[WO_4(NiOH)]^{2-}{}_{ads}$:

1. $WO_4^{2-} + NiOH_{ads} \rightarrow [WO_4(NiOH)]^{2-}{}_{ads.}$
2. $[WO_4(NiOH)]^{2-}{}_{ads.} + e^- \rightarrow [WO_4(NiOH)]^{3-}{}_{ads.}$ (limiting stage)
3. $[WO_4(NiOH)]^{3-}{}_{ads.} + 4H_2O + 6e^- \rightarrow W^0 + Ni^0 + 9OH^-$ (fast phasic process)

According to this mechanism, the reason of oxygen-containing tungsten compounds formation in the coating may be the behavior deviation of some part of intermediate compound $[WO_4(NiOH)]^{3-}{}_{ads.}$ from the equation 3 and its reduction not to metallic tungsten but to intermediate oxides. A considerable energy (high current density or temperature) is required for $[WO_4(NiOH)]^{3-}{}_{ads.}$ electroreduction, and the lack of energy leads to oxygen-containing compounds formation. The insufficient nickel ions concentration or insufficient cathode potential my be the reason of incomplete reduction of refractory metal ions. In more details this work is described in [7].

Taking into account these conclusions a research directed on determination of pyrophosphate electrolyte composition and electrodeposition regime of Ni-W coatings without cracks and impurities. As a result the technology of electroplating of nickel-tungsten alloy with tungsten content 28-30 wt.% and microhardness 7.0 GPa has been developed. The corrosion rate of the alloy was estimated to be 0.005 mm/year.

4 OXIDE COATING ON TITANIUM

The EDSO method consists in anodic treatment of vent metals, e.g. titanium, during that nanosize particles are embedded in oxide coating. Usually the coatings, obtained by anodic treatment have significant porosity (fig. 1), that in some cases may course pitting corrosion. When nanosize particles are introduced in coating formation zone they are captured by the pore entries, thanks to this the most of the pores are closed. This greatly increases mechanical and anticorrosion properties of the coating. The pores infilling with corrosion resistant alloys, e.g. Ni-W, seems to be the another method of porosity elimination.

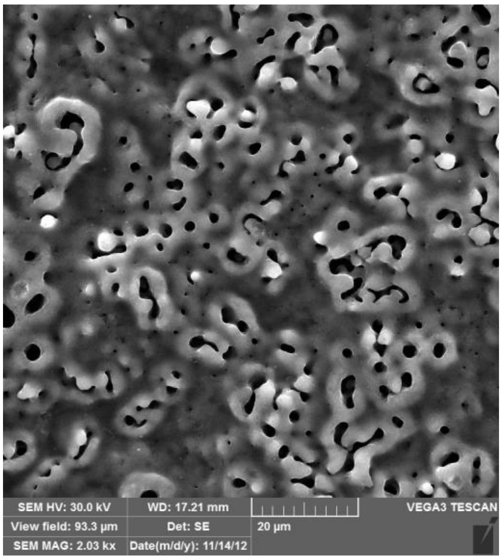


Fig. 1. Morphology of the coating obtained on titanium VT1-0 by microarc oxidization.

A nanosized corundum powder with main fraction 5 – 10 nm was used as a filler material for EDSO technology. A complex research of chemical and phase composition of coatings obtained was carried out before their cold resistance testing. The chemical composition of the coatings obtained by classic microarc oxidizing and EDSO-technology is represented in fig. 2 and in tables 1 and 2. Corundum is to be noted to present in the coating not in nanoparticles form, but in form of agglomerates with diameter about 5 mkm.

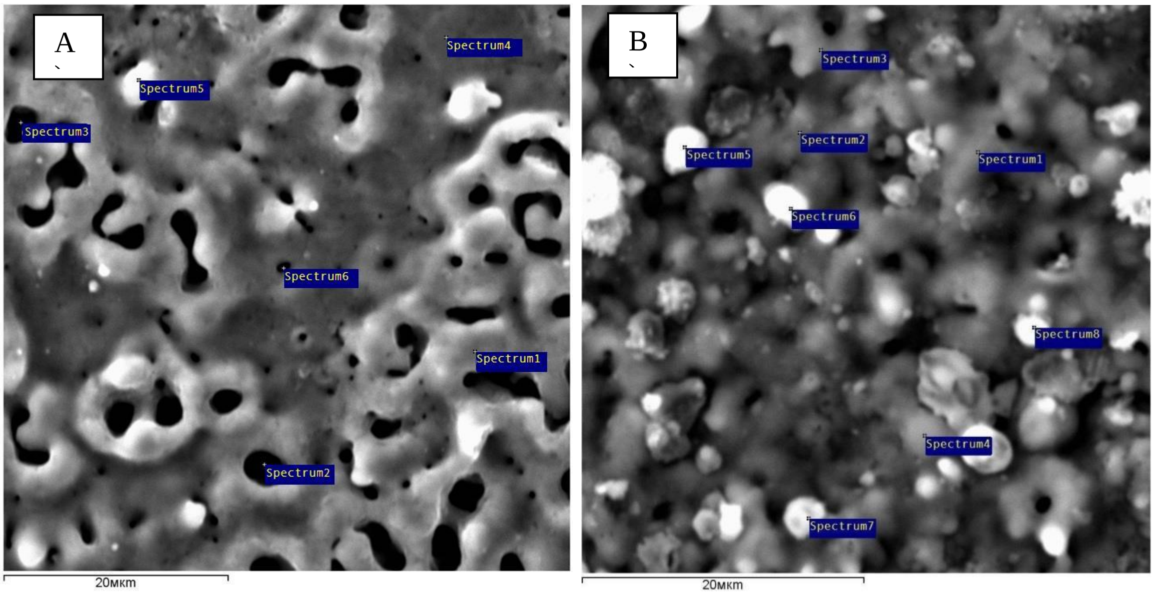


Fig. 2. Points, selected for energy dispersive microanalysis of coating chemical composition. A) coating formed by microarc oxidization; B) coating formed by EDSO. Specter interpretation is represented in tables 1 and 2.

Table 1. Chemical composition of the coating formed by microarc oxidization.

Spectrum	O, wt.%	P, wt.%	Ti, wt.%
Spectrum 1	41.57	1.29	57.14
Spectrum 2	-	0.92	99.08
Spectrum 3	-	1.54	98.46
Spectrum 4	41.69	1.33	56.98
Spectrum 5	60.77	1.57	37.66
Spectrum 6	40.09	1.42	58.49
Whole area spectrum	46.12	1.39	52.49

Table 2. Chemical composition of the coating formed by EDSO.

Spectrum	O, wt.%	Na, wt.%	Al, wt.%	Si, wt.%	P, wt.%	K, wt.%	Ti, wt.%
Spectrum 1	56.98	0.17	3.71	20.04	1.11	0.25	17.74
Spectrum 2	59.50	0.21	2.85	13.84	1.08	0.29	22.24
Spectrum 3	51.72	0.16	3.11	18.88	1.00	0.35	24.77
Spectrum 4	60.08	0.25	3.17	19.19	1.01	0.40	15.89
Spectrum 5	63.21	1.55	5.91	20.99	1.10	1.94	4.97
Spectrum 6	60.44	1.55	7.30	22.92	1.14	1.71	4.93
Spectrum 7	63.78	1.30	3.27	19.87	1.00	1.61	8.64
Spectrum 8	64.29	1.97	2.95	22.99	1.34	2.20	4.25
Whole area spectrum	55.62	0.70	3.88	18.88	0.96	0.88	19.07

The X-ray diffraction analysis of the coatings obtained shows that nanocorundum introduction in the electrolyte changes their phase composition. Except corundum incorporation into the coating changing of predominant phase takes place that may be explained by changes in physic-chemical processes occurring during coating formation. Mass present of each phase of the coatings are presented in tables 3 and 4.

Table 3. Phase composition of the coating formed by microarc oxidization.

Phase	Mass content, %
Rutile	11,8
$Ti_{0,98}O_{1,89}(OH)_{0,10}$	11,2
Anatase	77,0

Table 4. Phase composition of the coating formed by EDSO.

Phase	Mass content, %
Rutile	45,4
$Ti_{0,98}O_{1,89}(OH)_{0,10}$	10,5
Anatase	31,8
Corundum	12,5

Due to difference in thermal-expansion coefficients of metals and oxides temperature drops may lead to cracking of the coating. The incorporated into the oxide particles may work as stress concentrators thereby low temperatures are more critical for coatings obtained by EDSO. Hence, it was expedient to investigate if cracks appear in the coatings on the samples exposed to cold.

Thirstily, the investigation of classic coatings, formed by microarc oxidization without nanoparticles introduction, was carried out. In this case a technology prevoisly developed in FSUE CRISM “Prometey” was used. The experiment was carried out in climatic chamber under -50 ^{o}C during 24 hours. The coating samples investigations conducted with SEM before and after the exposing at low temperatures showed the absence of microcracks and other defects in arctic conditions. This allowed to turn to EDSO-formed coatings test. The morphology investigation after climatic test carried out with SEM (fig. 3) sowed that these ceramic coatings are resistant to low temperatures influence.

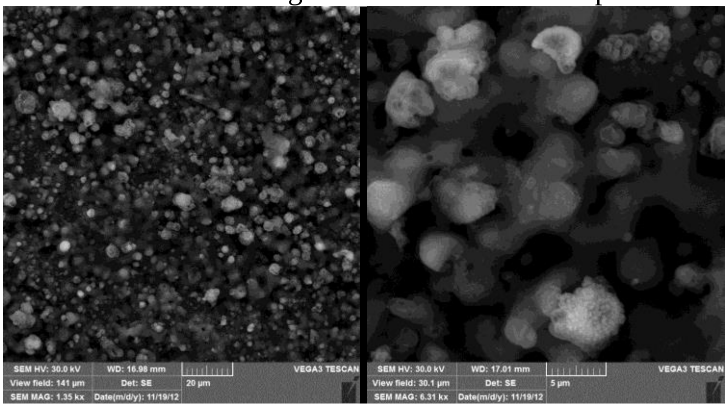


Fig. 3 EDSO-formed coating morphology after climatic tests.

The pore infilling with corrosion-resistant alloy is the alternative to embedment of nanosized particles into the oxide coating. A series of works was carried out in FSUE CRISM “Prometey” and a new method of Ni-W alloy electrodeposition in oxide coatings pores was developed. The experiments of the aforesaid coatings showed, that they also provide the high resistance to the low temperature influence.

The important advantage of the methods developed is the fact that such can be formed not only on the titanium but on any other vent metals e.g. on aluminum and its alloys.

5 SUMMARY

The process of nickel and tungsten ions joint discharge from pyrophosphate electrolyte have being investigated that allowed to develop the technology of plating hard corrosion-resistant Ni-W coatings. The method of ceramic coatings formation (titanium dioxide/corundum) is developed and such coatings are shown to be cold resistant. The method of cermet coatings TiO_2/Ni-W on titanium was developed.

Work was done under a partnership agreement "Development of materials and technologies for the Arctic" from 02.01.2012 with Lappeenranta University of Technology.

References

[1] *Vas’ko A.T. Electrochemistry of molybdenum and tungsten. Kiev: Naukova dumka, 1977. 172 p.*

[3] *Gamburg Yu.D., Gor’unov G.E., L’ahov B.F. Features of electrochemichal synthesis, structure and properties of nickel-tungsten-hydrogen triple systems. // Electrochemistry. 2011. V. 47. No 2. pp. 222-224.*

[4] *Schloßmacher P., Yamasaki T. Structural Analysis of Electroplated Amorphous-Nanocrystalline Ni-W. // Microchimica Acta. 2000. V. 132. No 2-4. pp. 309-313.*

[5] *Eliaz N., Sridhar T.M., Gileadi E. Synthesis and Characterization of Nickel Tungsten Alloys by Electrodeposition. // Electrochimica Acta. 2005. V. 50. pp. 2893–2904.*

[6] *Tohru Yamasaki. High-strength Nanocrystalline Ni-W Alloys Produced by Electrodeposition. // Mater. Phys. Mech. 2000. V. 1. P. 127-132.*

[7] *A.V.Krasikov. Electrodeposition of nickel-tungsten alloy from pyrophosphate electrolyte. Abstract of thesis for degree of doctor of Ch. Sc., The St Petersburg Technological Institute (Technical University). 2012. 20 p.*

Examination of Resistance to Brittle and Ductile Fracture of High-Strength Steels Using New Procedures of Mechanical Testing

Gusev M.A., Ilyin A.V., Larionov A.V.

Structural integrity department
FSUE CRISM "Prometey"
Saint-Petersburg, 191015, Russia
VictorM@crism.ru

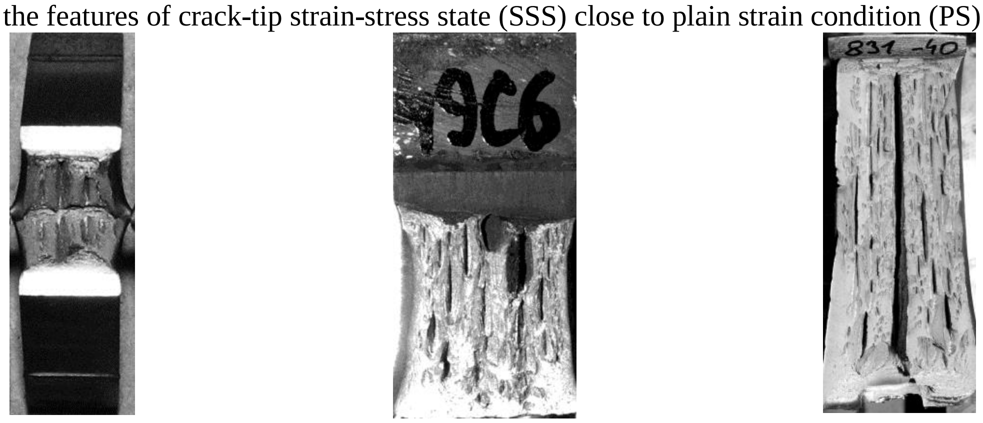
Abstract

The application of advanced CTOA and instrumented DWT-test techniques for determining of brittle and ductile fracture resistance of low-alloy cold-resistant steels is under investigation. The authors note that one of the problems of interpreting TMCP steels standard tests results is steel separating. Therefore it is proposed that methods which take into account integral fracture energy of full-thickness specimens should be used. Two methods are presented in this article. The first one consists in the determination of critical crack-tip opening angle (CTOA) at the stages of its stable propagation by using instrumented and optical techniques. The second method includes instrumented DWT-test with registration of specimens fracture energy and using modified specimens for the determination of CTOA by DWT-test. The results of modern low-alloy cold-resistant steels tests and comparison of the results obtained by two methods are presented.

6 INTRODUCTION

The work is fulfilled by FSUE CRISM «Prometey» as part of the Partnership Agreement «Arctic Materials Technologies Development» dtd. 01.02.2012 with the Lappeenranta University of Technology.

The current trend of metallurgy development is the use of thermomechanical controlled processing (TMCP) to produce steels with increasing strength and rolled sheet thickness. It provides a considerable saving in energy and lower expensive alloying elements contents in relation to traditional quenching and tempering (Q + T) technology. However, the materials produced by this way are more structural anisotropic as compared to Q+T steels. It appears as a specific type of fracture with some amount of separations observed in specimens (Fig. 1) at various types of testing (Charpy test, fracture toughness test, DWTT probes). Modern steels usually have high purity in nonmetallic inclusions and therefore the separations are not due to metallurgical defects. This effect should be considered to result from lower resistance to cleavage in the Z-direction (perpendicular to sheet plane) specific to TMCP steels and the features of crack-tip strain-stress state (SSS) close to plain strain condition (PS).



a) b) c)

Figure 1. Fractures of TMCP steels at a) Charpy test, b) static fracture toughness test, c) DWT test.

According to the results of well-known FEM numerical solutions [1], the σ_Y stress component near crack tip at PS (in the direction perpendicular to crack planes) reaches $(3.2\div3.5)\sigma_{Ye}$ when the σ_Z component reaches about $2.4\sigma_Y$ only where σ_{Ye} is the yield strength. It causes the crack propagation in its plane for homogeneous materials (i.e. perpendicular to the maximum stress σ_Y). But for nonhomogeneous materials where the stress in the Z-direction may be critical the separations at temperatures above the critical brittle-to-ductile temperature (T_{x1} in Fig. 2) become possible. In this case there is some temperature interval of ductile fractures accompanied by separations. They reduce near crack-tip stress constraint that causes brittle-ductile transition temperature decreasing (Fig. 2). On the other hand, separations may reduce ductile fracture energy and lead to possible early extended structures failure.

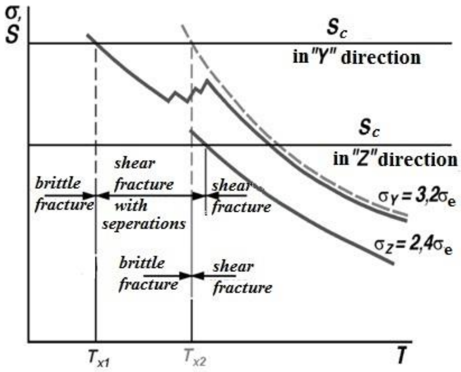


Figure 2. Expected mechanism of crack-tip separation formation for nonhomogeneous TMCP materials.

The quantitative assessment of permissible structural heterogeneity for sheet products requires full-thickness tests of metal with the determination of parameters which consider integrally fracture propagation energy. Such techniques are developed in FSUE CRISM “Prometey”. They include both static loading tests with the determination of critical crack-tip opening angle (CTOA at the stage of crack stable propagation and an instrumented variant of DWT test (drop-weight tearing test of a notched specimen) with the determination of fracture energy.

7 CRACK-TIP OPENING ANGLE (CTOA) DETERMINATION

The determination of CTOA is of increasing interest now. This parameter is considered as a measure of material stable ductile crack propagation resistance. The critical value of CTOA is used successfully in the aerospace industry to estimate ductile fracture toughness for thin-sheet aluminum alloys. This parameter is also perspective for the description of TMCP steels behavior during extended ductile fracture propagation in gas pipelines. There are some theoretical developments connecting CTOA with the velocity of ductile crack propagation in gas pipelines [2]. But today there is no unified standardized technique for CTOA determination applicable to thick-sheet materials (more than 20 mm in thickness).

Today, two approaches for CTOA determination are referred to in the literature. The first one is connected with the direct optical measurement of an angle on the specimen surface [3-5]. The second one is connected with an instrument-calculated method, which bases on the assumption that so-called rotating factor is constant [5-8]. The developed technique combines both these approaches. Tests are carried out according to a three-point bending scheme using specimens with an increased width-to-thickness ratio in relation to standard specimens: Bx(4÷4.5)B where B is the thickness (Fig. 3a). Time, load (P), notch-opening displacement on the specimen surface (V) and near crack tip (U) as well as load line displacement (the specimen deflection Q) data are recorded during the test. Periodical partial unloadings are made after the crack extension. After each partial unloading the surface of specimen is photographed with the resolution of 2560x1920 pixels. The grid with a step of 1 mm was previously drawn up on the specimen surface to measure CTOA optically.

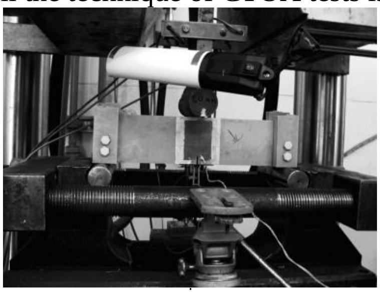
Instrument-calculated CTOA values were found from the load vs. displacement curves according to the formula recommended in the work [6]:

$$CTOA_c = \frac{8 \cdot r^*}{\xi} \cdot \frac{180}{\pi} \quad (1)$$

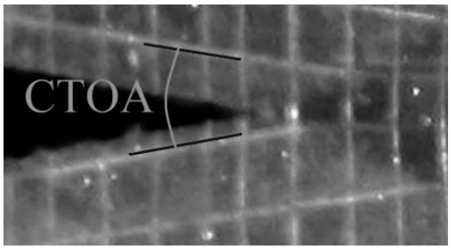
where r^* is the rotating factor; ξ is the slope of $\ln\left(\frac{P}{P_{max}}\right)$ vs. $\left(\frac{Q-Q_{max}}{S}\right)$ dependence; P, P_{max} are the current and maximum loads, respectively, Q is the current displacement; Q_{max} is the displacement at maximum load; S is the span between bearings.

There are a number of approaches for CTOA optical determination. One of them is schematically shown in Fig. 3b. Here, the angle formed by the grid lines near the crack tip is accepted as CTOA.

In more detail the technique of CTOA tests is described in the previous author's paper [9].



a)



b)

Figure 3. CTOA test: a) the specimen mounting on the test machine; b) the principle of CTOA optical determination.

The sheets made of pipe steel grades X70, X80 and X100 produced by TMCP (both strips and pipe material) had been tested. Both full- and half-thickness specimens were made from the sheets to study the influence of specimen thickness on the CTOA results. The tests were carried out at -20, +20 and +60ºC. The results of tests are presented in Table 1.

Table 1. CTOA results for different materials

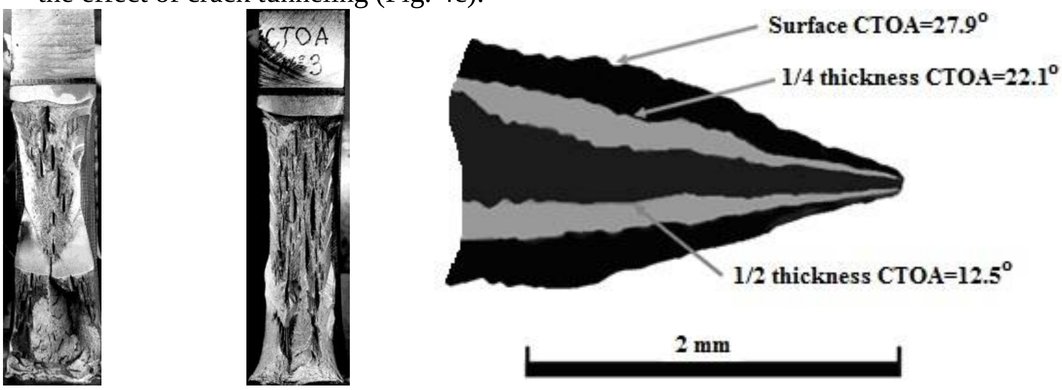
№	Material	Specimen thickness, mm	Test temperature,ºC	CTOA, deg	
				Instrumental method	Optical method
1	Strip X70	26	+20	20.7	-
2			-20	11.9	-
3	Strip X70	13	+20	22.4	-
4			-20	19.8	-
5			+60	25.7	-
6	Pipe X80	24	+20	17.5	23.4
7			-20	11.0	17.9
8	Pipe X100	17	+20	13.1	-
9			-20	10.4	-

These test results allow us to make the following conclusions:

1) The CTOA parameter decreases when test temperature is reduced. This decrease can be explained by a considerable increase in the separations found on the fracture area (Fig.4a and

4b). As a quantitative measure of tendency to separations it is possible to accept the ratio of their total extent on the fracture surface with stable CTOA to the area of this region [mm/mm^2]. For specimens made of X80 pipe material this characteristic makes: 0.064 1/mm for a temperature of +20ºC and 0.189 1/mm for a temperature of - 20ºC, so it increases almost 3 times. Corresponding CTOA values fall approximately 1.5 times.

2) The highest value of CTOA is obtained at a temperature of +60 ºC. At this test temperature separations are completely absent, therefore the value obtained of CTOA can be considered as the limit value of this characteristic for an ideal-ductile material behavior.
3) The increase of CTOA value with the thickness reduction for specimen with constant sizes ratio (Bx4B) is related to the smaller number of separations.
4) CTOA decreases with an increase in material strength. Obviously, this result is connected with a decrease in deformation ability for a stronger material.
5) The difference between optical and instrumental methods of CTOA measurement is related to the effect of crack tunneling (Fig. 4c).



a) b) c)

Figure 4. Fracture SENB Bx4.5B specimen cut from X80 grade pipe 27 mm thick at T_t=+20 ºC (a) and -20 ºC(b) and through-thickness distribution of CTOA values in specimen tested at T_t=+20 ºC (c)

8 INSTRUMENTED DWT TEST

The traditional technique of DWT test with fracture appearance determination gives control of transition to the brittle state of material, but does not allow us to make the conclusions concerning the ductile fracture energy. Separations can be recorded only, but the quantitative criteria of their admissible density or sizes are not clear. Therefore the instrumented test techniques allowing us to find the fracture energy of a specimen become promising. In FSUE CRISM “Prometey” the laser measuring system is realized. It determines the total fracture energy for DWTT specimen. The method is based on laser measurement of momentary displacement velocity for a dropping weight with the subsequent determination of fracture work vs. displacement relation (Fig. 5).

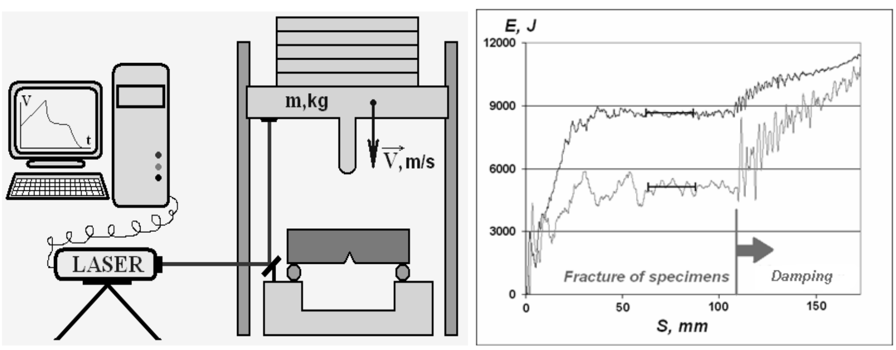


Figure 5. Laser system for DWT instrumented tests.

There are some difficulties with the interpretation of DWTT specimens fracture appearance for modern TMCP steels and the standard method of fracture appearance estimations is rather subjective. The fracture energy of a specimen also correlates with the type of fracture but it leads to an objective assessment. Fig. 6 shows the results of DWTT fracture energy determination for some modern cold-resistant high-strength steels. Fracture energy vs. temperature curve can be used to find the brittle-to-ductile transition temperature.

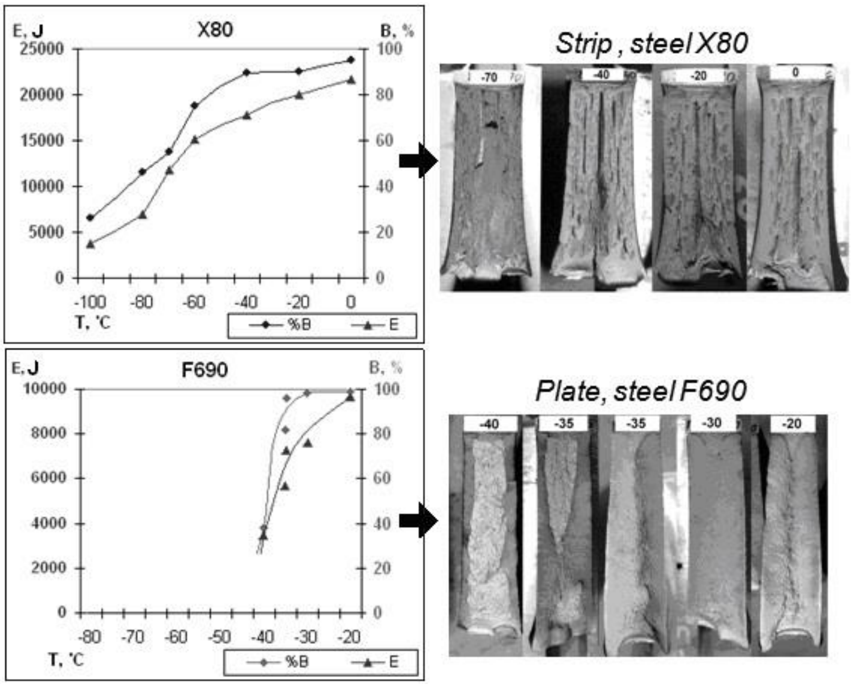


Figure 6. Fracture energy and shear area vs. temperature curves for DWTT specimens

There is the possibility of CTOA determination with using the instrumented DWTT techniques. However, for this purpose it is necessary to determine not only the total fracture energy but also to separate its parts to initiate and to propagate fracture. In [2] the method of two specimens differing in the width of net-sections "W – *a*" (W is the width of a specimen, *a* is the notch or crack length) for the calculation of CTOA values is described. This method is based on the dependence of fracture energy on "W – *a*". We offer the other method to determine a CTOA value. It is based on the tests of modified DWTT specimens with brittle deposit with a notch which minimizes a contribution of crack initiation energy (Fig. 7). Fig. 8 shows the comparison of fracture energy measurements for standard and modified specimens cut from pipe X80 grade. A nearly constant difference between these values confirms the possibility to consider it as a crack initiation energy which does not depend on test temperature.

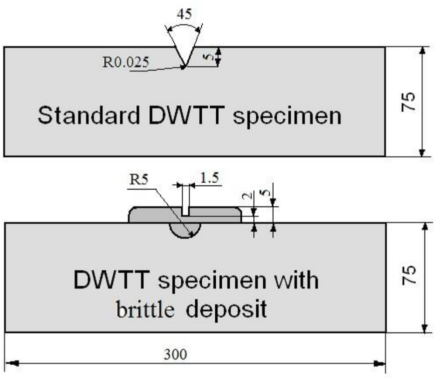


Figure 7. Modified DWTT specimen with brittle deposit.

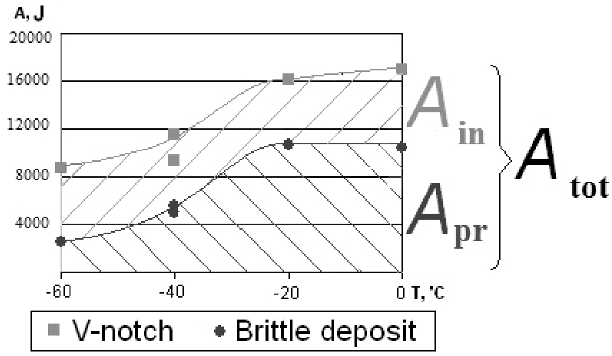


Figure 8. Total fracture energy ($A_{tot,}$, standard specimens) and crack propagation energy (specimens with brittle deposit, A_{pr}) vs. temperature.

To find the relations between CTOA and A_{pr} values as a first approximation let us accept that *CTOA* = const = α during crack propagation and the formula (1) is correct from the maximum load to the final failure of a specimen. Then the quantity A_p is determined as the integral:

$$A_{pr} = \int_{Q\max}^{\infty} P(Q)dQ, \tag{2}$$

where according to the formula (1), the dependence P vs. Q on the falling-down region of a deformation diagram is determined as:

$$P = P_{\max} \exp\left(\frac{(Q_{\max} - Q)8r^*}{S\alpha}\right). \tag{3}$$

Accepting that r* = 0.5 and carrying out integration, we will obtain: $A_{pr} = P_{\max}S\alpha$. Then using the relationship between the quantity $P_{\max}$ and specimen sizes: thickness *B*, width *W*, notch depth a_0 and ultimate strength σ_m, and expressing the CTOA value in degrees, we will obtain:

$$CTOA = \frac{180^0}{\pi} \frac{4A_{pr}}{k\sigma_m B(W - a_0)^2}, \tag{4}$$

where *k* is the factor, taking into account the constraint effect for specimen. The formula obtained corresponds to that in [2]; their equality is provided if we take k = 1.55.

The CTOA values obtained by this way for X80 grade steel are: 13.7º at 0ºC, 14.1º at-20 ºC, 7.3º at -40ºC, 3,3º at - 60ºC. They are rather close to those obtained at static load tests (closer to the results obtained by the instrumental method). This conclusion coincides with the results given in [5] and testifies to the relative independence of CTOA on the loading rate during test.

9 CONCLUSION

The developed test methods, namely, the crack-tip opening angle CTOA measurement at static load, the fracture energy measurement and CTOA assessment at dynamic load are rather simple procedures and may be used as certification tests in mechanical test laboratories to check the TMCP metal quality. In future these test results allow us to formulate the requirements for admissible structural heterogeneity of material based on reliability assessment for structures.

References

[1] *B.Z.Margolin, A.G.Gulenko, V.A.Shvetsova Improved probabilistic model for fracture toughness prediction for nuclear pressure vessel steels. Int. J.Pres. Ves. & Piping 75 - (1998) 843-855.*

[2] *The development and validation of a dynamic fracture propagation model for gas transmission pipelines/ P.E. O'Donoghue, M.F.Kanninen, G.Demofonti, S.Venzi// Int.J.Pres.Ves.& Piping 70- (1997) 11-25.*

[3] *CTOA results for X65 and X100 pipeline steels: influence of displacement rate/ R. Reuven e.a // Proceedings of IPC 2008, Calgary Alberta*

[4] *Fracture mechanics testing on specimens with low constraint––standardisation activities within ISO and ASTM/ K-H. Schwable e.a. // Engng. Fract. Mech. – 2005. – V.70. – P. 557-576.*

[5] *Measurement of CTOA of pipe steels using MDCB and DWTT specimens/ S.Xu e.a. // Proceedings of IPC 2010, Calgary Alberta*

[6] *Simplified single-specimen method for evaluating CTOA / S.Xu, R. Bouchard, W.R. Tyson // Engng. Fract. Mech. – 2007. – V.74. – P. 2459-2464.*

[7] *Review of CTOA as a measure of ductile fracture toughness/ L.N. Pussegoda e.a. // Proceedings of IPC 2000, Calgary Alberta*

[8] *Tearing modulus, J-integral, CTOA and crack profile shape obtained from the load-displacement curve only/ A. Martinelly, S. Venzi// Engng. Fract. Mech. – 1996. – V.53 № 2. – P. 263-277.*

[9] *Development of methods for determining the critical-tip-opening-angle (CTOA) as the resistance characteristics of the main ductile fracture of pipe metal. Vinogradov O.P., Gusev M.A., Ilyin A.V. – Voprosy Materialovedeniya, 2012, №2 (70), p. 150-160.*

Improving Product Information Management in Global Project Based Manufacturing

Niko Lipiäinen, Jorma Papinniemi and Lea Hannola

School of Industrial Engineering and Management,
Lappeenranta University of Technology
P.O. Box 20, FIN-53851, Lappeenranta, Finland

Abstract

Project based manufacturing typically contains large amount of diverse product related information. Efficient management of information is a key factor in gaining competitive advantage. For the nature of business environment, there is a need to take into account the special characteristics of project management. This study is based on a literature review on two areas, characteristics of project based manufacturing and product information management through lifecycle. These topics are covered by discovering the key concepts and some useful tools for improvements, like Business Process Management Notation. By combining the findings from the literature review, a framework is created to systematically improve product information management in global project based manufacturing.

Keywords: product information management, product lifecycle management, PLM, project based manufacturing

1 INTRODUCTION

Project based manufacturing is moving towards lifecycle business in global networks, setting up challenges for companies to manage their businesses in this new operating environment. When a company operates with turnkey sales-delivery projects, the whole project can be seen as an 'extended product' taking into account all product lifecycle information. One field to tackle these challenges is the successful Product Lifecycle Management (PLM) [1, 2]. PLM is an integrative information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life and its environment, from its design through manufacture, deployment and maintenance. Product Data Management (PDM) is a systematic, directed set of tools by which an industrially manufactured product is managed and developed. Information systems of PDM and with wider frame oriented PLM systems are based on a data model, to enable accessing, updating, manipulating and reasoning about product information that is being produced in a fragmented and distributed environment [1, 3].

The objective of this research paper is to find out ways and methods on how product information management could be improved considering the whole product lifecycle, especially in global project based manufacturing? The study starts with the literature review containing aspects of global project based business, product information management, and also some suitable methods and systems available for product information management. Based on this literature review, a new framework is created to improve product information management in global project based manufacturing. The improvement process with this model is based on systematic approach from the current situation towards the target state. In the global project based manufacturing, one of the main objectives for improvements is determined by the integrated, concurrent and Lean management of product and project information.

2 CHARACTERISTICS OF PROJECT BASED MANUFACTURING

One definition of a project is that it is a set of complex, coordinated activities with a clearly defined objective, and it can be achieved with a predetermined amount of financial and human resources and through synergetic, coordinated efforts within a given time [4]. In project management conditions, it is possible to use techniques, like clear goal, time schedule, clear framework, and predefined end product [5]. Common variables which are manageable in project environment are quality, time, costs and resources [4].

The wider view of the project lifecycle consists actions from the ideation phase to the support of usage. The actual project execution is in the middle of the lifecycle and contains combinations of different kinds of sub-processes or phases. These phases are beginning, design, execution, guidance and ending. At the beginning, needed activities might be the identification of needs, definitions of goals and setting timetables for a project. Also a risk analysis would help to recognize possible risks and their effects to the goals. At the design phase, required tasks and resources for the project will be identified. [6]

In the rational approach, breakdown structures and logical hierarchical structures are used in project management, because they replicate human mind by breaking down problems into sub-problems and enable to analyze projects at a greater level of detail [4]. At more complex projects, it becomes more important to manage various project structures in order to handle the generated data, and thus it looks like each industry has developed their own approaches to structure their products and projects [7]. From the chronological point of view, project management contains two stages, planning as well as control and reporting. Planning stage precedes the operational activities and it defines all the operational variables which are budgeting, scheduling and resource allocations [4].

Familiarity with knowledge management, coordination among employees and departments, incentive for knowledge efforts, authority to perform knowledge activities, system for handling knowledge, and cultural support are the six identified critical factors for knowledge management in project based business [8]. From the quality management perspective, barriers for an information flow can be organizational structures of a company, persons and posts which are linked to behavioral characteristics, and also technical barriers which are mainly related to information systems [9].

Project communications management requires very effective use of project information. One tool to support this is the communication requirement analysis, which provides the sum of information needs for project stakeholders. Typically, the requirements of project communications contain issues like organization charts, internal and external information needs, and also stakeholder information [10]. The information types, which may be included in Engineer to Order (ETO) projects, can vary in a large scale. By using the ETO Product Family Model, sub-phases of a project receive required information from a product family model and produce certain information for later phases [11].

3 PRODUCT INFORMATION MANAGEMENT THROUGH LIFECYCLE

The definitions of *product data and product information* refer in this context to the definitions of Sääksvuori and Immonen [1]. Their definition contains information broadly related to a product. Product information is also roughly divided into three groups. These groups are definition data of a product, lifecycle data of a product and also metadata that describes a product and lifecycle data.

Lean thinking and Lean principles are usually implemented in a manufacturing environment. However, they are also useful in the PLM context. E.g. information management, which enables and adds the value of information, can be seen as a potential target for the lean approach. The non-value adding waste, which lean thinking should eliminate, can be for example waiting, defects and corrections, unnecessary movements and non-commonality of components. Also issues like avoiding the excess time of finding and achieving the right information and utilizing the work which is already done, are related to the waste management of the Lean approach. [12]

Especially in customer-oriented engineering to order networks, design and product information have an important role. The challenges from a process perspective can be seen as understanding the context and reasoning behind decisions which are made earlier. From the *repeatability point of view,* a challenge is to have a common shared information perspective and coordination in information exchange, flow and reuse. From the *knowledge role perspective,* a challenge is the collaboration with knowledge producers and users. From the *knowledge information repositories point of view,* a challenge is to take into account the earlier mentioned perspectives as well as organizational and human factors. [13]

Lack of efficient product information management might lead to a *vicious circle* where problems feed each other. These problems might be e.g. the large number of items and the numerous laborious assignments caused by the maintenance of item information and product data. A reason for slow information retrieval may be that it is scattered over different systems which cause inaccuracy to the information updating. Methods to break the circle are e.g. improvement harmonization of the modes of actions, standardization, and reducing general hassle. [12]

Complexity is a good term to describe the processes throughout the entire product lifecycle. Besides modeling, designing, integrating, automating, monitoring and optimizing these processes, there is also a need for supporting variant levels of collaboration to improve effectiveness and efficiency throughout the entire product lifecycle [14]. When considering *modularity* in the complex project business environment, it mostly means understanding of company's own product and how it connects to other parts of the system [15].

In the literature, there has also been found many other *benefits to pursuit modularity in business*. E.g. direct positive effects to cost, quality, flexibility and cycle time performances have been discovered [16]. One of the biggest benefits in the ETO environment is its ability to reduce complexity by reducing significantly technical and organizational interfaces which project manager needs to handle [15]. By modularity is standardization of both products and production possible to get economies of scale benefit, and also by prefabrication is possibility to achieve productivity improvements. As an approach modularity provides both, flexibility and structure. [17]

Modularity might also bring some injurious effects, like sub-optimization. Because a modular architecture allows the optimization of local performance characteristics, but global performance characteristics can only be optimized through an integral architecture. One solution for this is the usage of a phase integration which may contain integrative design teams and transportation coordinators. [15, 18]

4 CREATING A FRAMEWORK FOR DEVELOPMENT PROCESS

The approach to improve product information management should be systematic that it would return desired results. However, the wanted outcome of the improvements may not be clear at the starting point. Thus, improvements should be seen as an iterative process in the complex environment of product information management. The complexity causes that building a framework in this context is a challenging task. By combining earlier theories of PLM and project business management, it is however possible to build a framework to improve product information management.

4.1 Theories behind the development process

Based on the product lifecycle management system model of Sääksvuori and Immonen [1], the system can be seen as a common and central databank of a company's functions and properties. Because in the project based business these functions and properties are very tightly linked to the different phases of project lifecycle, the product lifecycle management in this environment should be considered as integrated approach with project lifecycle management. As Artto et al. [6] and Tonchia [4] represent, there are several different phases of projects. These phases contain internal processes which are more or less similar through different projects.

Because information plays a crucial role in project and product management, it should be taken seriously into account. Lots of product and project related information are produced and required during the lifecycle. To identify these information requirements and the current situation, a good starting point is process modeling. One structured method for process modeling is Business Process Management Notation (BPMN). BPMN is noted as a suitable tool also for describing the information side of the processes [19]. In this way it also fulfills at least partly Project Management Institute's [10] listed needs for communication requirement analysis. To gather enough information about processes and requirements, Nuseibeh and Easterbrook [20] have listed useful techniques for requirements elicitation, like interviews and usage of existing documents.

When the business environment is the project based ETO manufacturing, the process modeling naturally follows the stages of a project lifecycle. To get maximized benefits of the models for information management, they should all describe the dimensions of the product information too. Oduoza and Harris [21] have described these product information dimensions in their information and knowledge framework. Even these knowledge dimensions are gathered and used during certain stages of the project lifecycle, they support each other and the knowledge can be reused at other stages as well. Briére-Côté et al. [11] show an example of this knowledge reuse in their comprehensive model of the sales-delivery process of ETO products.

Efficient reuse of knowledge also means that there is not any waste at information processes. According to Papinniemi et al. [12], by applying Lean approach it would help to improve knowledge reuse in PLM context too. For finding and analyzing waste, Stark [2] has collected a useful list of possible waste sources related to PLM, which can cause this kind of inefficiency. Depending of the case situation, there may also be a need for different analysis perspectives as well. From the process improvement point of view, Woll et al. [22] have described functionalities of the weak spot analysis. Other useful tools for process and product analysis are listed by Hvam et al. [23].

Woll et al. [22] are using in their process improvement framework four phases: 1) getting a holistic view of current situation, 2) an analysis on how situation can be improved, 3) designing the wanted situation and 4) creating steps how to reach the improvements. Oduoza and Harris [21] use at their knowledge management framework a little bit similar approach. They both start by identifying current state and end by execution. In addition, one more product knowledge oriented framework is represented by Hvam et al. [23] as a procedure for building product models. Also Hicks et al. [24] are identified three ways to improve relationships between business processes in ETO companies which are common databases, modular configurations and proactive procurement.

4.2 New framework for product information management

Figure 1 illustrates a new framework for improving product information management, based on similar frameworks as earlier mentioned, and is implemented to the ETO product information environment. Used frameworks are focused only to process or product knowledge management improvements, thus customized framework is created to take special characteristics of ETO manufacturing into account. In this framework it is done by combining principles of project related process management and product information management.

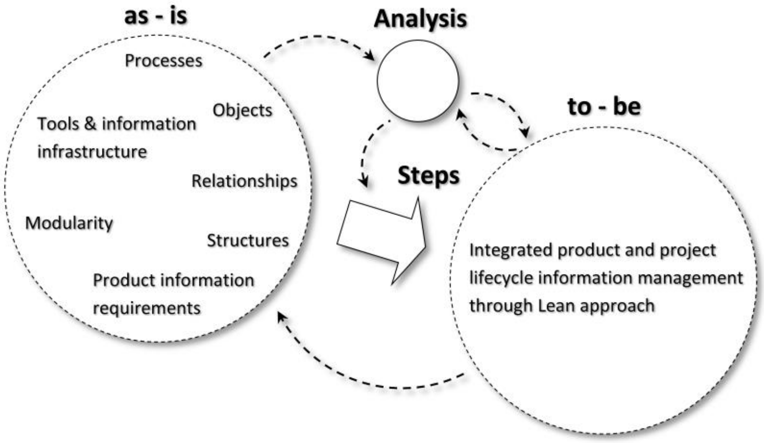


Figure 1. Framework to improve product information management.

In this framework, the wanted goal will be defined by analyzing current situation. This should lead to realistic and incremental improvements, because it is based on existing environment. Based on Oduoza and Harris [21], Briére-Côté et al. [11] and Papinniemi et al. [12], the general goal in ETO manufacturing can be seen as integrated product and project lifecycle information management through the Lean approach. After the wanted status is analyzed and approved, it is time to form steps to achieve the goal. These steps should be rational guidelines for improvements and they should also contain measurement components for evaluating achieved benefits of the improvements. One way to measure efficiency of improvements is using indicators which are mentioned by Grieves [3], and Sääksvuori and Immonen [1].

The new framework is composed of four phases. *Gathering the view of current situation is the first phase* of the framework. If there is not already a studied situation of product information management, the whole mapping process have to start from scratch. The issues which should be considered for getting a holistic view are processes, objects, relationships, structures, product information requirements, modularity, and also tools & information infrastructure. *An analysis of the current situation is the second phase* of the framework. At this phase, the collected information is processed to find information gaps. Because current situation of product information management contain process and information perspectives, they both should be analyzed. For example, if some process requires information which is not currently easily available, or if product data is inadequate because product structures are not well defined. By applying elements of the Lean approach, it is also possible to identify more efficient ways to resource usage. *The third phase is the development of a wanted status.* Just like in the process improvement framework, the wanted situation can be based on improved, already made as-is model. If the improvements require modular solutions, should be careful that it does not lead to sub-optimization. After the wanted status is developed, it is recommended to analyze the proposal for possible errors and to make needed changes to to-be model. *The final phase is creating the needed steps to achieve the goal.* In this phase is good to divide and group the objectives. By using long-term objectives and short-term sub-objectives for them, it is possible to create a structured approach for the development process. This phase also contains the definition of needed measurement components. Depending on the area of improvements, the indicators should be chosen in a way that they measure accurately the effects of improvements. The outcome of these phases is a new improved state in product information management.

5 DISCUSSION AND CONCLUSIONS

Because it is almost impossible to create a perfect solution which solves all needs of product information management in this changing world, the improvement should be seen more as a process than a single project. This leads to the situation where improvement is continuous and responding to real world. To support the process based approach, there is a loop back from to-be status to as-is status. When earlier determined situation is achieved, it comes naturally to current situation. Because situation is probably well documented, improvement process is easier to continue than starting it from scratch.

As a theoretical contribution, this paper provides a new framework for improving product information management in the project based manufacturing business. The new framework is based on the earlier literature related to product information management and project based business. The benefits of the new framework are that it gives a systematic approach and useful tools to improve product information management. The model can be used in ETO based manufacturing companies which aim to improve their product information management. The developed framework for improving product information management is focused especially to global project based manufacturing. Thus, using this framework in other contexts should be cautious. Future research is needed to find and analyze more suitable tools to the different phases of the framework. Also applying the framework into empirical context with several iterative cycles could prove its effectiveness in real environment of project based manufacturing.

References

[1] *Sääksvuori, A. & Immonen, A. Product lifecycle management. Third Edition. Heidelberg: Springer Berlin Heidelberg, 2008. 253 p. ISBN 978-3-540-78173-8.*

[2] *Stark, J. 2011. Product Lifecycle Management. London: Springer London. 561 p. ISBN 978-0-85729-546-0.*

[3] *Grieves, M. Product lifecycle management. New York: McGraw-Hill, 2006. 319 p. ISBN 0-07-145230-3.*

[4] *Tonchia, S. Industrial project management: Planning, design, and construction. Heidelberg: Springer Berlin Heidelberg. 2008. 229 p. ISBN 978-3-540-77542-3.*

[5] *Bruijn, H., Heuvelhof, E. & Veld, R. Process management: Why project management fails in complex decision making processes. Second edition. Heidelberg: Springer Berlin Heidelberg, 2010. 171 p. ISBN 978-3-642-13940-6.*

[6] *Artto, K., Martinsuo, M. & Kujala, J. Projektiliiketoiminta. Helsinki: WSOY, 2006. 416 p. ISBN 951-0-31482-X.*

[7] *Hameri, A. & Nitter, P. Engineering data management through different breakdown structures in a large-scale project. International Journal of Project Management, 2002. Volume 20 Issue 5. pp. 375-384.*

[8] *Ajmal, M., Helo, P. & Kekäle, T. Critical factors for knowledge management in project business. Journal of Knowledge Management, 2010. Volume 14 Issue 1. pp. 156-168.*

[9] *Lou, G., Zeng, S. & Tam, V. 2007. Managing information flows for quality improvement of projects. Measuring Business Excellence. Volume 11 Issue 3. pp. 30-40.*

[10] *Project Management Institute. A guide to the project management body of knowledge. Third Edition. Newtown Square: Project Management Institute, 2004. 390 p. ISBN 978-1-930699-45-8.*

[11] *Briére-Côté, A., Rivest, L. & Desrochers, A. Adaptive generic product structure modelling for design reuse in engineer-to-order products. Computers in Industry, 2010. Volume 61 Issue 1. pp. 53-65.*

[12] *Papinniemi, J., Ishii, K. & Kärkkäinen, H. 2011. Applying Lean thinking and principles in the context of PLM. The Proceedings of the XXII ISPIM Conference. ISBN 978-952-265-092-4.*

[13] *Silventoinen, A., Denger, A., Lampela, H. & Papinniemi, J. Challenges of information reuse in customer-oriented ETO networks. 2012. 5th International Conference on Mass Customization and Personalization in Central Europe. Novi sad, Serbia. September 19-21, 2012.*

[14] *Ming, X., Yan, J., Lu, W. & Ma, D. Technology solutions for collaborative product lifecycle management – Status review and future trend. Concurrent Engineering, 2005. Volume 13 Number 4. pp. 311-319.*

[15] *Hellström, M. Business concepts based on modularity – A clinical inquiry into the business of delivering projects. Åbo: Åbo Akademi University Press, 2005. 189 p. ISBN 951-765-294-1.*

[16] *Jacobs, M., Vickery, S. & Droge, C. The effects of product modularity on competitive performance: Do integration strategies mediate the relationship?. International Journal of Operations & Production Management, 2007. Volume 27 Issue 10. pp. 1046-1068.*

[17] *Hellström, M. & Wikström, K. Project business concepts based on modularity – improved manoeuvrability through unstable structures. International Journal of Project Management, 2005. Volume 23 Issue 5. pp. 392-397.*

[18] *Ulrich, K. The role of product architecture in the manufacturing firm. Research Policy, 1995. Volume 24 Issue 3. pp. 419-440.*

[19] *Cull, R. & Eldabi, T. 2010. A hybrid approach to workflow modeling. Journal of Enterprise Information Management. Volume 23 Issue 3. pp. 268-281.*

[20] *Nuseibeh, B. & Easterbrook, S. Requirements engineering: A roadmap. ICSE '00 Proceedings of the Conference on The Future of Software Engineering, 2000. pp. 35-46. ISBN 1-58113-253-0.*

[21] *Oduoza, C. & Harris, A. Knowledge management to support product development in cold roll-forming environment. The International Journal of Advanced Manufacturing Technology, 2011. Volume 57 Issue 5. pp. 585-596.*

[22] *Woll, R., Kind, C. & Stark, R. Continuous improvement of mechatronic product development processes. Modelling and Management of Engineering Processes, 2010. pp. 165-176. ISBN 978-1-84996-198-1.*

[23] *Hvam, L., Riis, J., Malis, M. & Hansen, B. A procedure for building product models. Moving into Mass Customization, 2002. pp. 19-39. ISBN 3-540-43611-1.*

[24] *Hicks, C., McGovern, T. & Earl, C. 2000. Supply chain management: A strategic issue in engineer to order manufacturing. International Journal of Production Economics. Volume 65 Issue 2. pp. 179-190.*

Laser Technology Synthesis of Composite Materials Based on Nanostructured Powder Materials for the Creation, Restoration and Repair of Complex Parts

Kuznetsov P.A., Vasilyeva O.V., Kudryavtseva I.V., Tereschenko A.V.

Department of nanostructured materials
FSUE CRISM "Prometey"
Saint-Petersburg, 191017, Russia
victorm@crism.ru

Abstract

Technological processes of selective laser sintering and cladding for the creation, restoration and repairing of complex parts are presented. It was shown that by using nanostructured powder materials based on Fe, Ni and Co-Cr can be obtained layers with high hardness up to 50 – 69 HRC.

1 INTRODUCTION

At the present time market demands new approaches and technologies which allow to obtain high quality goods and to reduce energy and material consumption. One of the most actual tasks at the present moment is the problem of hardening and recovery of heavy-duty parts and products in various fields of engineering, including arctic and agricultural machinery. For these purposes often use different technologies of cladding and surfacing. There is a number of cladding and surfacing technologies which is used different ways of energy supply to the base metal and different powder materials. Most of the technologies are relatively low deposition locality energy input, resulting in a heat affected zone of great thickness. This, in turn, causes a significant properties reduction of the hardened layer. In addition, the hardened layer is subjected by internal stresses, resulting in deformities of the work pieces. The above mentioned causes significantly restrict the use of such surfacing technologies as plasma, arc and flame.

Today in many countries are intensively developing technologies of producing complex parts and functional coatings from metal powder materials by using laser radiation. In order to obtain functional coatings, creation and restoration parts and products of complex geometry, including damaged during the operation, the technology of laser cladding and sintering of bulk objects are unique, allowing to receive given operational characteristics, defined geometric dimensions of parts and coatings, as well as the opportunity to receive new composite materials, even from immiscible components. Relating to parts recovery technology and coatings processes technology from metal powders, laser bulk cladding is considered as a promising method, one of which is technology LENS (Laser Engineered Net Shaping).

2 METHODS AND MATERIALS

Let us consider schematic bulk laser cladding process. High-power laser beam (Fig. 1) by focusing on a metal surface leads to forming a local microscopic liquid melt bath. Inert carrier gas argon is injected into the melt bath portion of the metal powder. After shifting of the laser beam the molten metal immediately solidifies, and by the addition of the powder into the molten bath the building part surface thickness is increased. Thus, as a result of a systematic scanning of the surface of the building part by a laser beam with simultaneous injection of powder are formed first and subsequent layers of the part which is being created. The given method allows you to use almost any metal powders and alloy powders that can be melted by a laser beam without evaporation.

Due to ultrafast crystallization of the melting bath the building part has ultra fine-grained or amorphous structure. According to the results of comparative tests on its mechanical properties, these parts are not only not inferior, but in some cases far exceed the parts obtained from similar alloys by traditional production methods (casting, stamping).

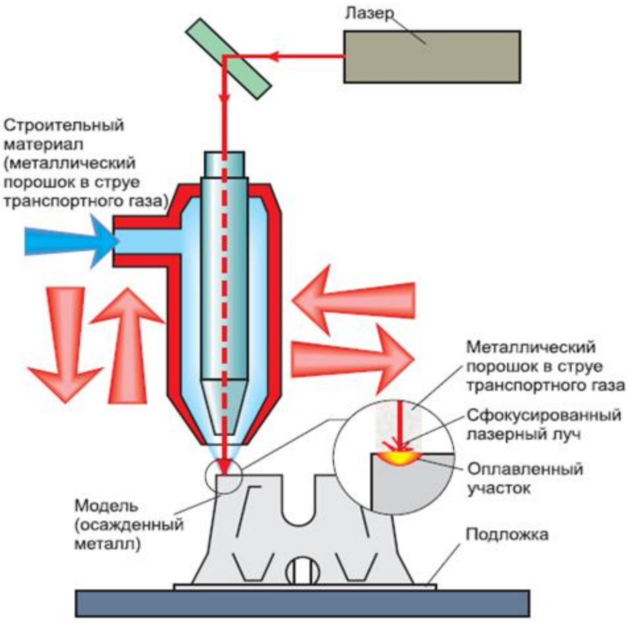


Figure 1. Scheme of LENS technology.

Table 1. Chemical composition of powders.

Element	R6M5	1560	PR-H30SRNDYU
Ni	-	73,3	1,46
Fe	80	3,7	55,1
Cr	3,5	14,8	32
B	-	3,1	1,9
Al	-	-	0,43
Si	-	4,3	3,6
V	1,7	-	-
W	7	-	-
Mo	6	-	-
C	-	0,8	4,9
Cu	-	-	0,48
Mn	-	-	1,2

For experiments on deposition of protective coatings by bulk laser cladding were selected following powders: R6M5, 1560 Hoganas, PR-H30SRNDYU JSC «Polema». The chemical composition of the powders was investigated by the X-ray fluorescence analysis and results are presented in Table 1. Plates were made from steel 20 and were used as the substrates.

3 RESULT AND DISCUSSION

Selection of optimum modes is to choose the laser power, substrate scanning speed, powder feeding rate, and the distance between the laser beam passes. Based on the experience working with similar chemical composition powders, LENS main parameters for each powder are summarized in Table 2.

SEM graphs of the coatings prepared in transverse direction are presented on figures 2-4. The results of Rockwell hardness measurements are summarized in Table 3.

Table 2. Powders cladding conditions.

Powder	Laser power, W	Substrate scanning speed, m/s	Feed rate, g/s	Hatch, mm
R6M5	400	0,013	0,23	0,23
1560	320	0,015	0,18	0,23
PR-H30SRNDYU	350	0,015	0,20	0,23

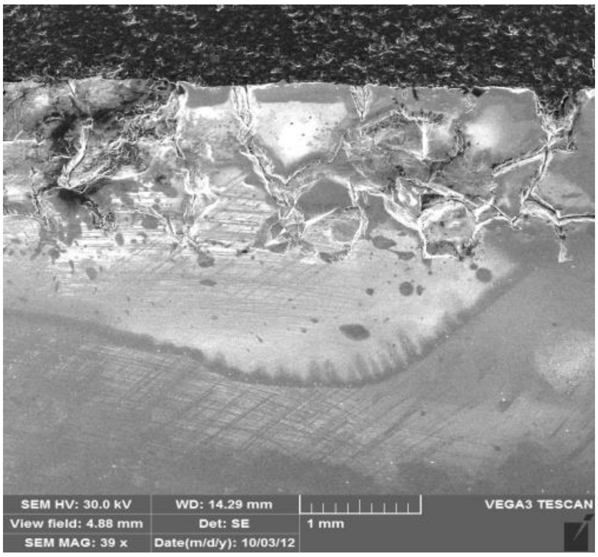


Figure 2. SEM graphs of the coating from JSC “Polema” powder.

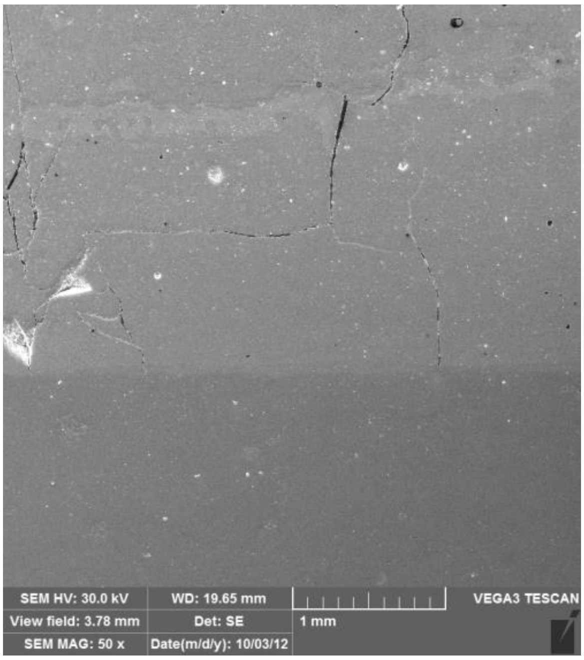


Figure 3. SEM graphs of the coating from 1560 powder.

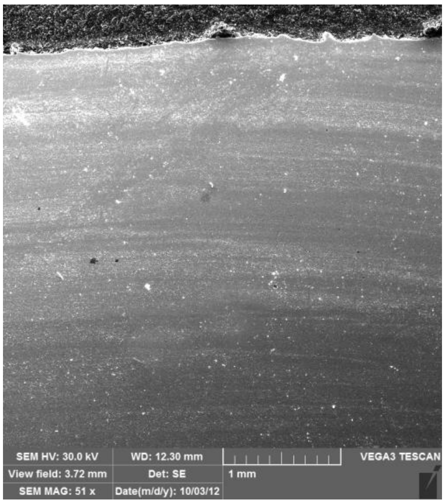


Figure 4. SEM graphs of the coating from R6M5 powder.

Table 3. Results of Rockwell hardness measurements.

Powder № measurment	R6M5	1560	PR-H30SRNDYU
1	61,6	65,1	67,4
2	61,8	64,6	68,6
3	61,4	65,9	67,9
Average	***61,6***	***65,2***	***68,0***

From the results obtained it is clear seen that the samples obtained from powders 1560 and PR-H30SRNDYU have the highest hardness but are fragile as evidenced by the cracks which are shown in fig. 2 and 3. Their formation is explained as follows: cladding with the direct feed of powder in the area of laser radiation leads to the formation of the structure which is increased amount of carbide and boride compounds. It affects the physical and mechanical properties of coatings. The formation of these compounds due to the presence in the chemical composition of powders carbide and boride generating elements, which confirms the tendency to cracking. Sample obtained from the powder brand R6M5, has a stable hardness at all points of measurement, and the absence of in the chemical composition carbide and boride generating elements has reduced the risk of cracking to a minimum (see Fig. 4).

4 SUMMARY

Analysis of the results leads to the conclusion that the most appropriate to use laser cladding powder with low-carbide and boride generating elements (eg R6M5), giving a surface high hardness and a reduced tendency to cracking.

Laser cladding technology LENS by high coating properties is the prospect of increasing the resistance of the most heavily loaded local areas of different parts of the Arctic and agricultural equipment.

In addition, the laser cladding can be successfully used for repair and rehabilitation of worn out sections of parts due to the high mechanical properties of the coating and the absence of deformation.

Work was done under a partnership agreement "Development of materials and technologies for the Arctic" from 02.01.2012 with Lappeenranta University of Technology.

References

[1] *Tereshchenko A.V., Bobyr V.V., Savin V.I., Kudryavtseva I.V., Vasilyeva O.V. Restoring a given geometry of machine parts and tools for technology selective laser sintering // Proceedings 14th International Scientific-Practical Conference "Technology of hardening, coating and repair: theory and practice" 17-20 April 2012 Abstracts. St. Petersburg. Part 1, pp. 178-181.*

[2] *Shishkovsky I.V. "Laser synthesis of functionally gradient mesostructures and bulk products" - Moscow: Fizmatlit, 2009 - p 424.*

[3] *Tereshchenko A.V., Bobyr V.V., Savin V.I., Kuznetsov P.A., Kudryavtseva I.V. "Creation of complex geometry parts by selective laser sintering of powder materials" // Proceedings of the 9th International Scientific and Technical Conference "Modern metal materials and technologies" on June 22-24, 2011., Proc. St. Petersburg.*

Lean, scalable and extendable ICT concept in a dynamically changing environment

Minna Lanz, Reijo Tuokko
Tampere University of Technology
Department of Production Engineering

Abstract

The paper outlines the challenges the Finnish industry has recognized during the past few years. The paper presents lean, scalable and extendable Manufacturing Execution System concept that has been created during industry-academia joint workshops. The concept aims to utilize different technologies while ensuring that the final and complex decision-making is done/approved by operators.

1 INTRODUCTION

New information systems have more and more dominant role in manufacturing industry. On one end there are Enterprise Resource Planning (ERP) and Product Data Management (PDM) systems and on the other end there are production machines and control architectures. Both of these have lately evolved thanks to the general advances in automation technology, information technology and the expansion of Internet technology. However, these systems have been developed from different perspectives and for different motives. The knowledge flow that should pass through these systems does not exist. The systems were built as stand-alone systems. Recently companies have different methods to close these knowledge flow gaps. The straightforward way is to use printed work orders to be attached to material lots. Special Excel applications are popular to manage load balancing and scheduling. Due to these short cuts for managing the knowledge flow, level of manual non-productive and non-value-adding work tends to rise too high. Several challenges with the IT architecture as a whole, integrations of sub-systems such as PDM and ERP and lack of common process and content models, taxonomies and semantics can prevent the efficient collaboration (Pulkkinen et al, 2013). This paper observes the challenges outlined by the Finnish metal industry from the manufacturing intelligence point of view.

Current ICT tools have been created for the old world where the mass-customization was a norm. However, as the business environment is becoming more dynamic and interconnected, the legacy systems can no longer to support fast moving high-tech companies. Therefore ICT must be adapted and re-configured as rapidly as the products the company produces. An example of such an ICT tools are complete and comprehensive PLM solutions for modern cyber physical machine systems. Among these solutions an example of the current state-of-the-art is Virtual Plateau (Dassault Aviation, 2013) developed by Dassault Aviation and Dassault Systemes. Even though these modern PLM solutions are a huge leap from last generation tools they still lacks some features essential for true data interoperability such as semantic data modeling which enables true context awareness. One shortcoming of these PLM systems, especially from the viewpoint of SMEs, is that they are massive closed one supplier ecosystems which tends to set initial as well as operating costs to too high level for SMEs also there rarely is adequate interoperability in between solutions of different vendors to enable SMEs to be flexible and agile enough.

2 BACKGROUND

Today the centralized knowledge management and decision-making systems are based on traditional standalone concepts that are highly optimized for achieving its goals in stable environment. However, as systems have become parts of bigger systems via cooperation and communication with each others, human and upper systems, what we have is not a predictably behaving stable environment. The state-of-the-art systems have achieved characteristic of a Natural System. The natural system is a system, where the environment evolves and changes over the time and the system itself evolves during its lifecycle. In order to operate in a dynamic and adaptive open complex environment we can no longer utilize hierarchical control paradigms, where the orders flow top-down layer by layer. Today's challenges require more sophisticated approach. One of these approaches is to adopt the characteristics of a natural system that supports the emergence. However, while the industrial world has seen the possible advantages, the implementations fall short as a result of the changes to the whole production paradigm that are required, going from preplanned hierarchical systems to adaptive and self-organizing complex systems (Chavalarias, 2006; Cotsaftis, 2009, Lanz et al 2012).

It is recognized that environment evolves and changes over the time and the system itself evolves during its lifecycle in order to survive in its environment. In order to operate in such dynamic and complex environment best of the both worlds; human intelligence and computers' computing power needs to be utilized in right places. As the unpredictable changes occur, detailed simulations of large systems become unreliable. Algorithms cannot solve the problems that arise, thus applying human intelligence to solve complex problems becomes highly important. Paradoxically the current operation strategy has forced human to be the processing unit while computer attempts to make intelligent decision over relatively vague input information.

A long-term development trend in project-based businesses, such as building construction, has been the integration around the product (and information needed to produce it) and applications for dynamic product assembly by temporary set up of companies so called virtual enterprises. The term virtual enterprise is still indicating the presence of enterprise product centered paradigm. However, it has already become fully evident, that the future needs in building digital content management go well beyond the enterprise product centered point of view, even if that would cover the whole building life-cycle including facilities management operation and maintenance.

The information in future will be retrieved from diverse sources originating from different circumstances and application. Therefore the resultant data are inherently built on different semantics that will put high demand on semantic integration solutions. Also, information will be fetched from diverse locations (over the global networks), which will be grounds for extensive use of web technologies. These two basic requirements (semantic integration, access over web) speaks for the adoption of semantic web technologies to describe and integrate (or perhaps rather inter-link) digital content on built environment. Poorly structured information is not useful as such since knowledge and business insight builds upon well-formed processes and structures. As a rule of thumb, successful industrial information management includes both encouraging good practices and avoiding bad ones.

The future systems envisioned must be connectable with other systems in the factory and provide visibility to the supply chain network (Lanz et al 2012; Järvenpää & Torvinen, 2013). There are arisen needs to develop and test new concepts for factory internal material handling where automated storages with identification of items stored (Lohtander & Varis, 2013). It is likewise envisioned how the various users could benefit from improved visibility to the location and availability of items and using this information throughout the supply chain to improve productivity. Attention is on handling line stock, tools and small series assembly/production where typical hurdles today are; finding the right materials, parts and tools at the right time, getting them to the correct location for assembly or production, errors in inventory balance, knowing when parts are ready and using this information for steering assembly and parts manufacturing. Further, possible benefits of making the real time inventory balance and trend of selected items in these storages available to different players in the supply chain need to be studied. As it is outlined, the needed information flow and system communication in order to realize the factories of future are integrating the previously stand-alone systems under one operational framework, where different views are offered to the different stakeholders during the realization of product-services (Lanz et al 2012; Huhtala et al 2013).

3 PARADIGM CHANGE

3.1 From narrow domains to Systems Thinking

Technical developments over the past decades have produced stand-alone systems where high performance is routinely reached. Cotsaftis (2009). This solid background has allowed the extension of these systems into networks of components each in charge of only a part of the system regardless the effect towards the holistic system. As the systems are process oriented instead of knowledge-oriented systems, the interaction between tasks cannot be modeled, thus the effect of single interactions and relationships cannot be represented in the full systems scale. The types of interactions are changing into a complex network of possibilities within certain limits instead of a steady and predefined process flow. This situation is relatively new and causes pressures to define the role of intended interaction.

In recent years, production system research has started to adopt ideas from complex systems. According to Bourgine & Johanson (2006), complex adaptive systems are non-linear systems with many strongly-coupled degrees of freedoms. They are composed of multiple, interacting autonomous units, such as agents, actors or individuals having adaptive capabilities. The adaptive capability is manifested by the ability of these multiple-component systems to learn and evolve based on internal and external dynamic interactions. The components and organizational structures are able to react to their environment and feedback, and adapt their functions to novel conditions and tasks. (Bourgine & Johnson 2006.) According to Fryer (2010), the control of complex adaptive systems is highly dispersed and decentralized and they are characterized by constant, self-organizing behavior in order to find the best fit with the operating environment.

Saarinen and Hämäläinen (2010) summarized the key features of the “systems” of system intelligence (i.e. complex systems) collected from the relevant: a) The behavior of the system displays features that cannot be obtained by summing up the behaviors of the isolated components, in other words the system can display emergence; b) The system has the ability to self-organize its components in order to create a new structure and, consequently, new behavior; c) In order to determine the overall behavior of the system, the relationships and interaction between parts, giving rise to patterns, regularities and complexity, are more important than an analysis of the properties of the individual parts in isolation; d) The systems are dynamic, showing changing states and behaviors during their lifecycle. These changes are often conceptualized in terms of functions or goals. Due to the nonlinearity of the system, a change in one component may have an unanticipated effect on other components, and on the behavior of the system as a whole. And finally e) The boundaries of these systems are re-definable, flexible and dependent on one’s perspective, and are artificially created by humans for the sake of clarity and sanity (Järvenpää, 2012).

3.2 Adding meaning to the context

Today, engineering design and product development process are seen either as tool independent methodological processes or, in the other extreme, the process is completely dominated by tool sets (i.e. software applications) used in it. Systems engineering related systematic approaches to simulation-based product development methodology address this problem field by introducing process models which rely on heavy use of computational engineering design tools and methods (Nykänen et al., 2012). Lanz et al (2012) introduced the modular ICT approach, where the core of the system of the system is based on semantic content information. While the knowledge representation in this case was static, it offered enough information for different services to operate. Järvenpää (2013) introduced a concept for capability adaptation, where semantic content and context information play key role. In capability-based adaptation, the product requirements are matched against the system capabilities and the system is adapted, until it satisfies the requirements of the product, i.e. until it is compatible with the new product requirements. Nylund and Andersson (2010) introduced a concept for content integrating framework allows integration of design and development activities of manufacturing operations and systems.

3.3 From Technology-based systems to Product-service systems

Newest trend among the evolving companies are the personalized product-service systems. The service orientation is seen to bring revenue to the companies in different life-cycle phases of a product or product family. For this it is essential to capture knowledge about interactions within a product-service system. Mont (2002) and Cavalieri (2012) offer examples of interactions were given such as customer interaction during product-service development and interaction between actors in the product-service value chain. There are many more interactions such as the physical and virtual interactions between the customer and different elements of the product-service, interactions within the product-service and the product-service within the system. Current research in interaction representation and capture has been motivated by different, and complex, driving factors such as loss of important information from workplace interactions due to lack of recorded analysis. An observation was made in (Whittaker, 2008) that research in the area has focused on technology rather than on user-centric issues or services that could increase the added value. This highlights the need to develop both methodologies and technologies for capturing interactions whilst ensuring that they meet the needs of all of the stakeholders within the product-service system. Furthermore as identified in (Schmidt, 2000) there are both implicit (actions performed by a user that are not primarily aimed at interacting with a system but which a system understands as such) and explicit human computer interactions where context of use plays an important role in the interpretation of the interactions that are taking place. Work conducted in Human Computer Interaction states that unless a system has some means of finding out what the user really knows and does a system will unable to interact with users cooperatively (Fischer, 2001).

4 SCALABLE, LEAN AND EXTENDABLE MES -CONCEPT

Lohtander & Varis (2012) concentrated on global distributed manufacturing environments and highlighted the importance of knowing the manufacturing capabilities of available suppliers when making product design decisions. The development of production systems in Finland has been shifting towards networked manufacturing while the main contractors have been focusing on their core businesses (Koivisto 1997). This development is still proceeding and it is seen one of the key elements of productivity growth (Nininmaa 2009, Teknologia teollisuus 2011). MES functions are broadly considered to be functions inside one factory or at best inside one enterprise. Therefore, in order to collect potential benefits of MES such as the reduction of errors, efficient use of equipment, improved planning, reduced order-to-ship times, etc. (Flakoll 2008) the MES functions would require to be extended to work within a network of manufacturing SME companies. The outlined sub-project of FIMECC's Future Digital Manufacturing Technologies and Systems (MANU) programme is named as Lean MES. The Lean MES concept was created during several industry-academia joint workshops.

- **Demand:** Today the need is to increase the productivity and efficiency in all levels at the same time it is needed to lower the cost generated from non-value adding processes. Current systems are based on stand-alone systems that do not communicate within the surrounding environment, which increases the cost of non-value added operations and thus slows down the value adding processes. Proposed concept will strengthen the Lean thinking in all levels of operation and thus reduce the non-value adding operations time and cost. Thus the project strengthens the SME's daily operations in highly networked environment by enhancing cross-system observation, planning and reacting to changes. Current approach aims for the top-down control architecture, where on system rules all. This is too heavy and expensive for SMEs. The concept outlines a novel MES concept for networked SMEs that allows them to observe, plan and react better in distributed and dynamic production environment, while at the same time support human operators to work and collaborate effectively in an evolving environment.

- **Ambition:** Scientific breakthrough is achieved by providing means for open interfaces, standards and modularity. The concept, once implemented as a novel software product, can be utilized in machine, system and network level operation management. This kind of software does not exist today
- **Outcome:** Lean, scalable and extendable concept for new type of MES that supports the human operator in a dynamically changing environment. The concept is verified in automatic, semiautomatic and manual case scenarios at machine, system and network level. The outlined concept can be shortly afterwards implemented as commercial tool for SMEs and in larger spectrum as the human friendly operation principles in any company.

The ultimate goal of the project is to provide lean, scalable and extendable concept for new type of MES that supports the human operator in a dynamically changing environment. This objective is reached by combining best of soft methods and hard technology, by understanding the cause and effects of a complex system, and thus, by continuously seeking to evolve through continuous improvement of processes and actions. This project's outcome is a concept for networked SMEs that allows them to observe, plan and react better in dynamic and highly networked production environment.

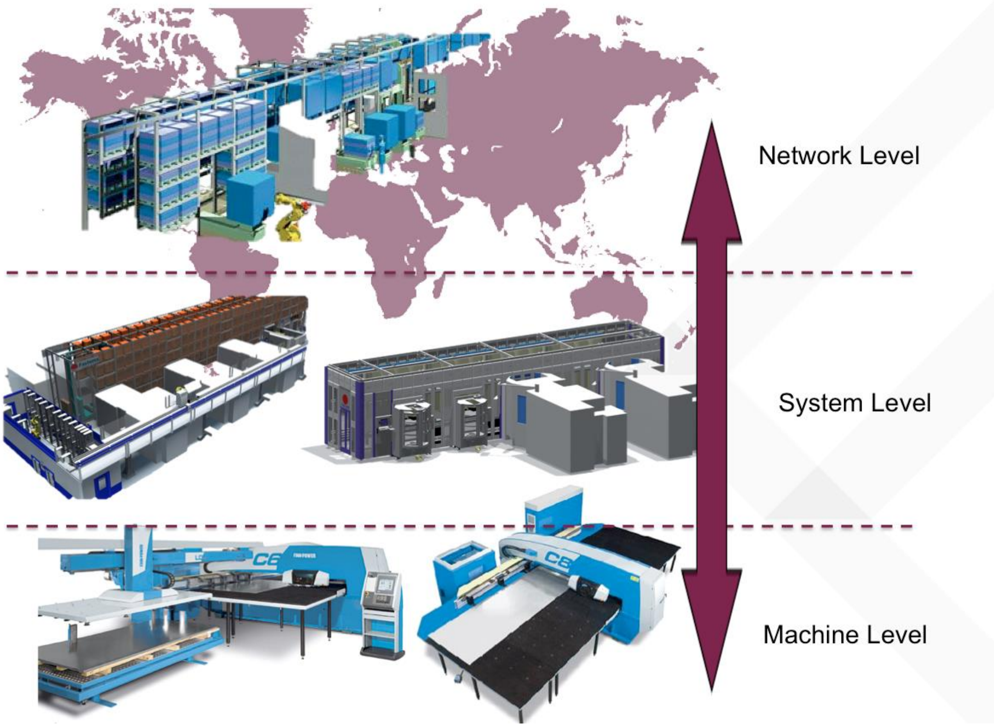


Figure 1. Lean MES concept provides support for automatic, semi-automatic and manual operations in machine, system and network level.

Lean framework model does not promote automation over the manual operations. This is based partly on philosophical ideas but it is also partly originated from practical reasons. During the time when lean-philosophy was created, the software technology and IT-infrastructure as general was much less advanced than it is now. At that time, the extensive use of computers on factory floor was simply very expensive but also added considerable risks for process interrupts.

One of the main goals of project is to investigate which novel technologies, software platforms and tools exist that conform to Lean ideas. The starting point is to respect lean principles and use software technology where it can be done in harmony with lean. It is also studied how community platforms could be used to facilitate and strengthen lean processes and lean implementation.

In the classical job shop problem, a number of jobs are to be scheduled on a number of machines in an arbitrary order (Pinedo, 1999). In the static problem, makespan (which is the time spent for a set of work orders from starting the work until the final order is completed) is usually minimized, but more realistic and especially dynamic versions may consider through-put time and due date related objectives. A practically relevant application of the problem is the assembly shop, where additional (timing) constraints are imposed on the schedule by tree shaped converging product and process structures. The job shop problem is notoriously difficult to solve, and various solving methods from simple heuristics to optimal enumeration methods have been used. One of the objectives of the project is to develop fast online production control methods for manufacturing execution systems. Systematic study on application of optimization in highly dynamic production environment has not been reported. Optimization study would enable development of high quality fast heuristics that take into account the status of the assembly shop. A flexible job shop, where choice between parallel machines has to be made is an important extension of the problem.

In order to realize connection between system and hardware special attention is paid to interfaces. Integration of the software of various components of a lean manufacturing system (e.g. NC machines, PLC, etc.) to a lean MES, and integration of it to external information systems (e.g. remote monitoring, ERP, etc.) is one important development target of lean manufacturing. Studies concerning application of OPC UA in lean manufacturing have not been reported yet. How to utilize OPC UA in such a system and what would be the benefit of this is currently an open research question. Answers to these questions are to be found in this project.

On the hardware side, one of the objectives of project is to control the knowledge flow and be able to track products and material locations that do affect to the production. In tracking and logistics, RFID is still future technology. RFID technology is rapidly being adopted by industry, mostly evolving in closed systems. For an implementation and use in a global supply chain setting, standardization efforts become necessary for technology on which RFID is based, such as radio frequencies, transmission protocols and data formats. The main challenge is the interoperability between different technologies and solutions. Thus, integration plays a very important role.

5 SUMMARY

The paper outlined the challenges the Finnish and global industry has recognized during the past few years. It has been understood among the small and agile companies and in large enterprises that the agility of operation distribution and reaction is important and it cannot be realized unless the operations and supporting systems are developed in such way that they support operations in changes. The paper presented a concept created during industry-academia workshops outlined lean, scalable and extendable Manufacturing Execution System concept that has been created during industry-academia joint workshops. The concept aims to utilize different technologies while ensuring that the final and complex decision-making is done/approved by operators.

References

Chavalarias, D., Aberer, K., Aurell, E., Babaoglu, O., Barrett, C., Bessiere, P., Bourgine, P., Caldarelli, G., Cardelli, L., Kasti, J., Cotsaftis, M., et al., Complex systems: Challenges and opportunities, an orientation paper for complex systems research in fp7, European Comisssion, 2006

Cotsaftis, M., A passage to complex systems, in Complex Systems and Self-organization Modelling, C. Bertelle, G. H. E. Duchamp, and H. Kadri-Dahmani, eds., Springer, 2009, p. 236.

Dassault Aviation, The Virtual Plateau, URL: http://www.dassault-aviation.com/en/aviation/innovation/the-digital-company/the-virtual-plateau.html?L=1, accessed 3/2013

Flakoll, R.: MES vs. ERP is it all jargon?, Manufacturing&Logistics IT, 2008

Fryer, P., 2010. A brief description of Complex Adaptive Systems and Complexity Theory. Available at: http://www.trojanmice.com/articles/complexadaptivesystems.htm [Accessed May 25, 2010].

Huhtala, M., Lohtander, M., and Varis, J., Manufacturability of sheet metal design with the help of Product Data Management (PDM), submitted to proceedings of Advanced Design and Manufacturing (ADM 2013), 2013

Järvenpää, E and Torvinen R., Capability-based approach for evaluating the impact of product requirement changes on the production system, Proceedings of Flexible Automation and Intelligent Manufacturing, FAIM2013, Portugal, Porto 2013

Järvenpää, E., Capability-based adaptation of production systems in a changing requirement, PhD Dissertation, Tampere University of Technology URL:http://URN.fi/URN:ISBN:978-952-15-2940-5, 2012

Koivisto, T. and Koski, K.: Asiakassuuntautunut, joustava ja verkottunut. Analyysi tuotantojärjestelmien ja osaamistarpeiden kehityssuunnista, 1997

Lanz, M., Järvenpää, E., Luostarinen, P., Garcia, F., and Tuokko, R., Towards Intelligent Assembly and Manufacturing Environment - Modular ICT support for Holonic Manufacturing System, Precision Assembly Technologies and Systems: 6th Ifip Wg 5.5 International Precision Assembly Seminar, Ipas 2012, Chamonix, France, February 12-15, 2012, Proceedings pp. 154-162

Lohtander, M. and Varis, J., "Collecting manufacturing information in a global distributed manufacturing environment", Mechanika, vol. 18, no. 1, pp. 84–88, Mar. 2012.

Nikinmaa, T.: Tuotannon verkostoituminen luo kasvumahdollisuuksea. Available at www.sitra.fi/artikkelit/2009/, 2009

Nykänen, O., Salonen, J., Markkula, M., Ranta, P., Rokala, M., Helminen, M., Alarotu, V., Nurmi, J., Palonen, T., Koskinen, K.T. and Pohjolainen, S., 2011. What do information reuse and automated processing require in engineering design? Semantic process. Journal of Industrial Engineering and Management vol. 4, num. 4, Universitat Politecnica de Catalunya.

Nylund, H. and Andersson, P., Simulation of service-oriented and distributed manufacturing systems, Robotics and Computer-Integrated Manufacturing, Volume 26, Issue 6, December 2010, Pages 622-628

Pinedo M, 1995, Scheduling: theory, algorithms, and systems, International Journal of Production Research, Vol. 45, 15, p. 3477-3503. Prentice Hall.

Pulkkinen, A., Rissanen, N. and Vainio, V., PLM state of the practice and future challenges in globally networked manufacturing companies, submitten to the 1st PDM forum for Finland-Russia collaboration, Lappeenranta 25th and 26th April 2013

Saarinen, E. and Hämäläinen, R.P., 2010. The Originality of Systems Intelligence. In: Hämäläinen, R.P. & Saarinen, E. (eds.), Essays on Systems Intelligence. Aalto University, School of Science and Technology, Systems Analysis Laboratory, pp. 9-26.

Teknologiateollisuus, Tuotanto ja palveluverkostot, Toimintasuunnitelma 2011, 2011

PLM state of the practice and future challenges in globally networked manufacturing companies

Antti Pulkkinen[1], Noora Rissanen[1], and Ville Vainio[1]

[1]Department of Production Engineering
Tampere University of Technology
P.O. Box 589, FIN- 33101 Tampere, Finland
firstname.surname@tut.fi

Abstract

In this paper we summarize some findings of research project (2010-2012), which studied the current PLM practices and the future PLM challenges of global manufacturing companies. The paper presents the challenges of studying a versatile topic and a method taking into account the several factors of business context. The results relate the mode of businesses to the PLM implementation processes, results of the process (i.,e. the current implementations of the companies) and future prospects of PLM in globally operating companies. The conclusion and discussion chapter presents our insight on the future challenges of globally networked companies.

The first research question is: what kind of PLM implementations appear to be common in Finnish large manufacturing companies? The second research question is: what appear to be the future PLM challenges for globally operating companies? For the both questions we applied qualitative research methods. We advise companies to align business structures and to integrate the modes of business along with implementing PLM. Typically the companies have had a set of consecutive PLM projects resulting in scattered legacy architectures. Recently, the companies have begun to harmonize the PLM applications. The most advance companies utilize product configuration, which can be seen as a driver for PLM development. The project based companies appear to struggle with recursive issues in consecutive development projects. The actual challenges appear to be the consolidation of industrial practices and process, the uncertainties of future, data flow in relation to PLM architecture, information quality, master data and engineering change management. These issues reflect the need of common, yet flexible PLM approach in networked companies.

1 INTRODUCTION

The topic of our research is the product life cycle management (PLM) in the context of globally operating organizations. We have recognized that some the companies are able to respond to the challenges of the context more successfully than others and our hypothesis is that the successful companies are further in the utilization of PLM due to alignment of products, processes and their support. Thus, an obvious research question is: what characterizes the companies' success and/or failure in the utilization of PLM? This is a practical problem, but difficult to study because the development and utilization of PLM takes long time and it is hardly repeatable. Also, the conditions framing the cases of development and utilization are hardly common. Therefore, the actual research questions of this article are:

What are the characteristics of implementation processes in companies?

What are the results of the implementation processes, i.e. PLM implementations, and what kind of business processes are characteristically supported by the processes?

What are the future PLM challenges of global companies?

After the introduction, we present briefly the research method and material, the findings of the research and the conclusions and discussion based on literature and the research.

1.1 The practical context of the research: PLM in global organizations

Within the recent decades the locally operating industries have transformed into nodes of globalized business networks. The characteristic sequence of the transformation takes place in three stages. The initial stage is the globalization of sales, the second stage of independent and globally distributed production and the third stage the international supply chains with worldwide, cross-functional collaboration [1]. Business processes that are realized by globally networked organizations require the efficient management of the objects of operations, organizations and content. All these objects are decomposable structures as the organizations form hierarchies and processes are composed of sub processes. Also contents, whether material or immaterial, are compositions of subsections such as assemblies and components, documents and data items. The structures and the objects belong to different domains and they are typically managed by different business functions using a variety of tools for supporting the functions. Moreover, the structures of the domains are different from each other and the relations between the objects of different domains are ambiguous. Thus, the management of the entirety of global business processes is a complicated challenge. Our research supports the idea that in the cases where the structures can be aligned as the integrated elements of business processes, standard designs and data items their co-ordination and management is easier than in the cases of disintegrated and separate structures.

1.2 The challenges, controversies and complexities of PLM research

The methodological challenges of PLM research are due to context and topic: complexity and unrepeatability. In an ideal situation the research of business strategies and structures in different domains would provide verified and valid, useful and needed knowledge for business managers. The knowledge should contain support for the decision making, whether the management challenge is about the finding of right strategies, processes, architectures or the most beneficial support for them in the circumstances of current and future situation. The making of rigorous collection of recipes is a dream hard to fulfill. Ideally, a researcher could conduct a set of experimental studies in finding the types of causal conditions required for making of the recipes. Of course, it is not viable option to experiment with such a costly, effort and time consuming issues as PLM. However, the different practitioners, such as consultants and industrialists, have provided a set of guidelines for the different domains of business. For example, for decision making in the development of PLM some rules have been laid out by Sääksvuori and Immonen [2], Stark [3] and Grieves [4]. Many have presented their deployment models [5, 6, 7, 8] and new integrating technologies [9, 10, 11], which are typically claimed to be proven in practice.

The manifestation of PLM is a Product Data Management (PDM) system. Following the model by Crnkovic et al. [5] we consider implementation as a sum of efforts taken in the evaluation of the needs, the selection of suitable solutions and the deploying of the solutions in practice. In the implementation of PDM it is essential to gain common comprehension of the system and to fit the system to the users' need [12]. However, this is a complicated task, because implementing and using PDM often causes efforts for a certain organizational function while the other function gains the most of benefits [3]. Thus, PDM supports the coping of dispositional mechanisms [13] between the business functions and serves as media of communication. Though, the implementation of PDM may cause resistance, loss of work in product development and friction in the collaboration of functions [14]. For the ease of implementation companies often use a set of pilot projects, but they do not always give reliable knowledge on the global utilization of PDM systems [12]. Several challenges with the IT architecture as a whole, integrations of sub-systems such as PDM and ERP and lack of common process and content models, taxonomies and semantics can prevent the efficient collaboration [10, 11, 15, 16, 17]. In some cases the results may actually turn out to be the opposite of the desired effect for business process. Apparently, there seems to be mismatches between the findings of different authors representing both industry and academia.

These examples of literature show that the studying of the success of the implementation of PLM and PDM is a complex task. The complexity can be defined as a factor depending ultimately on the interest of the researcher. This definition is similar to the definition of complexity by Ragin [18, p. 20] in social sciences. There, the complexity lies even within statistically proven facts, such as the relationship between economic dependency of nations and their economic growth [18]. In practice the statistical facts cannot be taken as guidelines of development. For example, the economical dependency of nations cannot be prohibited because of the negative indications of the effect on GNP (Gross National Productivity) according to statistical analyses. This may also be the case in the mismatch of studied implementation results, the desired effects on the business processes and the implementation models of literature. The message of different authors is dissimilar because the viewpoints and the interests of the authors are different.

1.3 The complexity related to the types of businesses

To understand the complexities of the utility of PLM implementation we have to have a better view on business. Traditionally, four different product types with different kinds of varying attributes in the product structure are presented [19]:

1. Standard products without variants
2. Standard products with variants
    a. defined by the company
    b. defined by the customer
3. One-of-a-kind product

Three generic business approaches are related to the above categorization of products and to the production volume. These are serial (mass) production to stock (MTS), customization (e.g. by applying configuration) of assemble or make to order product (ATO, MTO), and deliveries of engineer to order (ETO) projects. Naturally, configured products and ETO projects often include standard or configured components, such as fixed, modular or parametric items. [20] For reducing the complexity related to business management, e.g. in sales delivery, the utilization of modular product architectures has been recognized years ago [see e.g. 21].

Product architectures are related to many domains of product specifications ranging from functionality to technology and (physical) realization of a product [22]. Within the domains commonalities of product architectures (the composition of elements and relations) manifest virtues such as variety on the markets, increased commonality and reduced complexity, which are experienced within the life cycle stages [21]. A company chooses the stage of life cycle where it operates its business. From business point of view the modular architectures may deliver a set of sub-products that are easier to manage [22]. It is fair to assume that a company, which is able to utilize the product architectures in different kinds of businesses, has a better chance of succeeding in product management than a company, which cannot utilize the architectures, such as the set of common sub-products used in MTS, ATO, MTO and ETO types of business.

2 METHOD AND MATERIAL

For this article we studied six globally operating companies. The businesses of the companies were composed of marketing, engineering, production, maintenance and upgrading of mechatronic products. Hence, the material of the research covers all the phases of product life cycle and also the manufacturing and service businesses. Also the variety of the products was wide and the research is therefore about the most of engineering disciplines (mechanical, electrical, software, process, etc.). However, the focus of our research was in the support of engineering and sales-delivery processes.

The research procedures were planned in collaboration with the funding companies. The companies indicated interest in the benchmarking of each other. The collecting of the material was aligned with the interest of companies and the benchmarking procedure by Camp [23] was adopted in the initial set up of the research. First, we conducted a set of initial interviews in the companies in order to gain an insight on their level of maturity and willingness to share their experiences as well as their further interest in different issues related to PLM. Notes were taken in the interviews and a short report of each interview given to interviewee for correction. After the interviews, we arranged a benchmarking session in each of the six companies. In the selection of topics for the sessions the mutual interests and the willingness to share the experience played the key role.

Research material had been collected in the form of notes, transcribed audio recordings and collected presentation material. The material was further elevated as reports of each benchmarking session and framework of analysis. Selecting the suitable solution for the analysis of the material appeared as a challenge (see chapter 1.2). The chosen method was an adaptation of Qualitative Comparative Analysis [18] we called PLM Implementation Profile (PIP) see [24].

Another set of research material was collected in two idea-generation sessions. The sessions took place in two of the consulting / PLM vendor companies and a large group of industrialists, consultants and academics took part in them. The themes of the sessions were left loose, but e.g. initial interests were being collected. Also common challenges were being recognized. The main reflections of the sessions are briefly and directly reported here in order to reflect the future challenges of global PLM.

3 RESULTS

The operations of all of the benchmarked companies indicated several business types. However, some distinctive factors could be found. The PIP analysis indicated that three types of business modes were being found (Table 1). The distinctive factor seems to be the existence of standard products and their use in the different modes of sales delivery processes.

Table 1.Cases in relation to modes and types of business

The business mode	Cases	Offered product types & their relation	
integrated	A, B, C	All types, which...	are composed of each other
detached	D		are treated as independent
projects	E, F	Projects contain hierarchically nested variants	

The three modes are different by the utilization of re-used, common elements and their mutual relations. In the integrated mode an offered product can be a composition of other offered products. In the detached mode this was not clearly evident. Three companies represented the integrated mode, as they utilised standard/fixed products in configurations and configurations in project deliveries, i.e. projects were partially configured. Let us call them companies A, B and C. Only one company (D) represented the detached business mode, where different sales delivery processes and product types did exist, but they were not integrated. Within the approach of the company D there was no intention to systematically utilise the different kinds of products in other types of business (the case in the companies A, B & C). Two companies (E, F) of the project mode of business were similar to the integrated business, but their deliveries were always projects. ETO systems of projects often included systematically varied elements. Naturally, the suppliers of these companies supplied standard components to projects, but no standard or purely configured products were included in the offerings of the companies E and F.

3.1 What are the characteristics of implementation processes in companies?

Typically, the implementation of PLM takes long time, because it is composed of the set of consecutive implementation projects addressed on different topics. Many PLM initiatives have begun already in 1990's. It is remarkable that many of the companies (e.g. A & F) have been utilizing product configuration, parametric design models and knowledge based engineering systems as early as 1980's. A natural question is the comparison of the success and persistence of their PLM implementations.

Typically, IT systems have a life cycle and the content (knowledge, information and data) of the systems eventually stagnates to oblivion see [25]. However, some systems may be revived by upgrading the system and making the content persistent. Some companies have been able to maintain long life cycle of some pieces of engineering knowledge and product data (e.g. modules and items) within the upgraded systems. The difference between the revived (A & B) and stagnating (F) cases of IT and content appear to exist in the positive combination of the integrated business mode (e.g. company A). In the companies operating in the project mode the suitable of-the-shelf has been hard to find (company E) or the early implementations of PDM systems have disappeared (company F).

3.2 What are the results of the PLM implementation processes?

The companies of the integrated mode considered PDM&PLM systems essential for their business, while others had less the mature state of PLM implementation [26]. The most common PLM architecture was legacy architecture (in the companies A, B, D, E and F), where several pieces of software were loosely integrated [26]. However, in the integrated business type the several kinds of implementations were being recognized. Company C had implemented a single source PLM support from a vendor normally considered as an ERP provider. There the global product management relied on the agreements made between the local affiliates and the headquarters of the company. Also, the product was not mechanically as challenging as in other cases, which indicates the potential of modularity as previously presented. The companies A and B had several PDM and CAD systems integrated for the business needs. One of these companies was harmonizing its support to single source while the other remained to utilize legacy architecture. In all of the companies the life cycle support was important because of the increasing share of service business within their turnover.

In the case of detached business mode the company D had legacy PLM architecture, but the different branches of business had the specialized set of support. The data of MTS, ATO and ETO products were being managed by different systems. The PDM support was mainly targeted on the management of the items of configurable product families and the project based business of the company D lacked a modern PDM support. The company E had an in-house legacy PDM system and the other project based company (F) had a PLM system, but it was seldom actively used in project engineering. The support of standard products is mature in current PLM systems. Also, some PLM systems have begun to manage product variants, but the PLM support of project business seems to be immature.

3.3 What are the future PLM challenges of global companies?

Many legacy architectures are to be replaced with single source architecture. For example this is the case of the company C, D and E [26]. Also, service business is becoming more important, because the global markets of many companies are quite mature and the demand of new products is not increasing rapidly. The studied companies have made (company C) or are making (companies B, D & E) large changes in their PLM architecture. According to idea-generation sessions the most important areas of future development were related to practises, processes, data flow and quality as well as the integration of the actual engineering work and the IT-tools. Also, master data management and the change management of product structures and configuration knowledge were recognized as the most important future challenges. The architectural changes and the diversity of processes in different business modes raise questions that will be discussed in the next chapter.

4 CONCLUSIONS & DISCUSSION

Currently there are many approaches to implement single source PLM architecture. An accompanied one-size-fits-all process model is a challenge to the PLM implementation in the diversified modes of business. This is especially plausible in the detached and pure project modes of business. We advise companies to integrate the modes of businesses and provide common support for the development of re-usable, standardized designs. A beneficial situation would be, if the standard designs would also be the spare parts or assemblies of service business. In an ideal situation the different business processes would be using the standardized platform elements, but the different branches would require a different set of support. This requires the flexibility of PLM implementations, which is a challenge for global vendors, their local affiliates, consultants and manufacturing companies.

Apparently the presented hypotheses are correct as in a global company the diversified products, processes and organizations require aligned yet flexible PLM support. An indication of this is the companies of integrated business mode have been able to persistently utilize their PLM implementation with the common set of offerings despite of the diversity of business processes. The integrated business modes manifest the alignment of the structures of different domains. With this approach positive effects, such as late point differentiation, within production networks may be attained as indicated in [27]. Also, the chosen approach of the integrated mode of business is providing better support for the service business, because the standardized items / modules may serve as spare components in service operations. The identification of needed items is also possible with the approach as the item data is available. In the detached or pure project modes of business this is not an easy task, because the number of items to be managed is ever increasing without re-use and the design data quality of project engineering hardly meets the requirements of service business. Also, attaining the positive effects within production networks becomes harder. However, the consideration of structures is limited to the business modes, offered products, the success of PLM implementation and their relations. Thus, a hermeneutic research approach utilizing the presented methods may be advisable.

Acknowledgements
We acknowledge the effort, time and funding of the industrial companies and the efforts of other research institutes (Technical research center of Finland, VTT and University of Vaasa) that participated in the research project Fudge (see: https://wiki.tut.fi/Fudge/WebHome). We are also obliged to Fimecc's GP4Variants program for providing a network for the research (see: https://wiki.tut.fi/pub/Fudge/WebHome/GP4V_final_report.pdf) and Tekes' Digital Product Programme (see: http://www.hankegalleria.fi/tekes/?so_id=32615).

References

[1] Jacob F., Strube G. Why Go Global? The Multinational Imperative. In: Global Production - A Handbook for Strategy and Implementation. Edited by Eberhard Abele, Tobias Meyer, Ulrich Näher, Gernot Strube and Richard Sykes. Springer Verlag. 2008, pp. 2-33 ISBN-10: 3540716521

[2] Sääksvuori A., Immonen A. Product Lifecycle Management. Springer, 2008, , 266 pp. ISBN-13: 978-3540781738

[3] Stark J. Product Lifecycle Management: 21st Century Paradigm for Product Realisation. Springer, 2011. 581 pp. ISBN-13: 978-0857295453

[4] Grieves M. Product Lifecycle Management: Driving the Next Generation of Lean Thinking. McGraw-Hill, 2005. 288 pp. ISBN-13: 978-0071452304

[5] Crnkovic I., Asklund U., Dahlqvist A. P. Implementing and Integrating Product Data Management and Software Configuration Management. Boston. Artech House computing library. 2003. 366 pp. ISBN-13: 978-1580534987

[6] Murphy, R. A Framework for a COTS package implementation: as utilised at BAE Systems. Presentation in the 9th International Conference on Product Lifecycle Management. PLM09, 6-8 July 2009, Bath, UK.

[7] Navarro R., Cloonan J., Dubois R., Tiwari A. Improving efficiency in Product Lifecycle Management implementation projects by applying lean principles. . In: The proceedings of 11th International Conference on Product Lifecycle Management. Edited by J-H, Pels et al. , PLM 11, 11-13 July, 2011, Eindhoven University of Technology. 11 pp.

[8] Peruzzini M., Mengoni M., Germani M. PLM benefits for networked SMEs. . In: The proceedings of 11th International Conference on Product Lifecycle Management. Edited by J-H, Pels et al. , PLM 11, 11-13 July, 2011, Eindhoven University of Technology. 14 pp.

[9] Bergsjö, D., Malmqvist, J., & Ström, M. 2006. Architectures for Mechatronic Product Data Integration in PLM Systems.In: Proceedings of Design 2006, Dubrovnik, Croatia, pp. 1065-1076.

[10] M. Lanz, R. Rodriguez, P. Luostarinen, and R. Tuokko, "Neutral interface for assembly and manufacturing related knowledge exchange in heterogeneous design environment",

in Precision Assembly Technologies and Systems, S. Ratchev, Ed. Springer, 2010, pp. 21–29.

[11] Järvenpää, E., Luostarinen, P., Lanz, M., Garcia, F. & Tuokko, R. (2011). 'Dynamic Operation Environment - Towards Intelligent Adaptive Production Systems'. International Symposium of Assembly and Manufacturing (ISAM), 25-27 May 2011, Tampere, Finland. 6 pp.

[12] Bergsjö, D. 2011. PLM Adoption Through Statistical Analysis. In: The proceedings of 11th International Conference on Product Lifecycle Management. Edited by J-H, Pels et al. , PLM 11, 11-13 July, 2011, Eindhoven University of Technology. 9 pp.

[13] Olesen, J. Concurrent Development in Manufacturing - based on dispositional mechanisms. Ph.D. thesis. Institute for Engineering Design. Technical University of Denmark. 1992. 154 pp.

[14] Chen, S. C., Chen, R. J., Huang, J. M., Lin, W. T., Yang, C. C. 2006. Failure evaluation and the establishement of an improvement model for product data management introduced to enterprises. International Journal of Advanced Manufacturing Technologies. Springer-Verlag London Limited 2006. 15p.

[15] Ou-Yang, C., Chang, M. J. 2005. Developing an agent-based PDM/ERP collaboration system. International Journal of Advanced Manufacturing Technologies. Springer-Verlag London Limited 2005. 16p.

[16] Yang, J., Han, S., Grau, M., Mun, D. 2008. OpenPDM-based product data exchange among heterogeneous PDM systems in a distributed environment. International Journal of Advanced Manufacturing Technologies. Springer-Verlag London Limited 2008. 11p.

[17] Chango, L., Choon, S. L., Inhyuck, H., 2010. PDM and ERP integration methodology using digital manufacturing to support global manufacturing. International Journal of Advanced Manufacturing Technologies. Springer-Verlag London Limited 2010. 11p.

[18] Ragin C.C. The Comparative Method: Moving Beyond Qualitative and Quantitative Strategies. University of California Press, 1989. 218 pp. ISBN-13: 978-0520066182

[19] Schomburg.E. Entwicklung eines betriebstypologischen Instrumentariums zur systematischen Ermittlung der Anforderungen an EDV-gestützte Produktionsplanungs- und -steuerungssysteme im Maschinenbau. Diss., Aachen, 1980.

[20] Pulkkinen, A., Riitahuhta, A. On the relation of business processes and engineering change management. In: McMahon,C., Dutta, D. & Huang, G. (eds.). Proceedings of the 6th International Product Lifecycle Management conference, PLM09, 6-8 July 2009, Bath, UK 10 p.

[21] Riitahuhta, A., Andreasen, M.M. Configuration by Modularisation. In: the Proceedings "NordDesign '98", Stockholm, KTH, 1998. pp.167-176.

[22] Erens, F. Verhulst, K. Architectures for product families, In: Computers in Industry 33, 1997, pp.165-178

[23] Camp, R.C., Benchmarking – the search for industry"s best practices that lead to superior performance, American Society of Quality Control 17, Quality Press, Milwaukee, WI. 1989 320 pp. ISBN-13: 978-0527916350

[24] Rissanen N., Pulkkinen A., Vainio V.V. Testing a Framework for Analyzing PLM Architecture in Global Manufacturing Companies. In: FAIM 2012: Ferry Cruise Conference, Helsinki-Stockholm-Helsinki, 10-13th of June 2012. Edt. by Seppo Torvinen & Hasse Nylund.

[25] Aaltonen, A. Prosessilaitosten projektitoiminta. In Finnish: "The project operation of process plants". Raportti No. 52, 1995, Koneensuunnitelun laitos,Tampereen teknillinen korkeakoulu. 20 pp.

[26] Vainio V.V. Comparative research of PLM usage and architecture. M.Sc. thesis. Tampere University of Technology, 2012. 73 pp.

[27] Pulkkinen A., Huhtala P., Riitahuhta A. Integrating product structures, production processes and networks for the development of product families. In: Proceedings of NordDesign 2008 Conference, ;Tallinn;21-23 August 2008, pp. 161-170

Product Data Management and software automation in housing development: case Hartela Kide

I. Ville Rantanen

Department of Architecture
School of Arts, Design and Architecture
Aalto University
Espoo, Finland
ville.rantanen@aalto.fi

Abstract

This paper will explain how product data management and software automation were applied in a research and development project for construction company Hartela in Finland. The developed Kide-software is currently used by Hartela group to design and manage construction of dwellings, and as a tool for sales.
Building products used for construction and design of dwellings were divided into hierarchical categories based on their area of use, also defining the relations between products. A product database was established and integrated with the design software. Furniture layouts and pre-selected collections of products ("styles") were defined for common room categories and saved into the database. A verification algorithm was created to check that all product data definitions in the building information model (BIM) were correctly set and valid.

1 INTRODUCTION

The starting point for the work was a need to find an alternative practice for making substantial modifications to new buildings: it was usual, that kitchen cabinets were replaced and bathroom walls and floors retiled in newly completed apartments as the interior architecture did not meet the customers' expectations.

For customers, modifications caused additional cost and delay. For the construction company, extra work was needed and it was difficult to plan efficient schedules for consequent building projects as workforce were assigned to each project an unpredictable time period. To achieve a fast and efficient new construction process for customized apartments, a tool was needed for designing changes, calculating cost, automatizing purchases and the production of documentation and drawings.

More efficiency was also gained by standardizing product range and apartment designs. Software automation was created to assist design work as well as to create documents automatically. Allowing customers as much freedom as possible to make changes to the room layout within an apartment was also one of the key objectives. The pricing methods generally used in construction business had to be replaced with a new kind of pricing system: instead of compensating excluded products or work and calculating additional price for changes, products were priced with a fixed price. This required that general expenses of construction (design, marketing; construction of building exterior and common areas, dividing structures and structural members as well as HVAC systems) were included in a baseline price, whereas internal work and products were priced based on their direct expenses (purchase, transport and installation of products plus the profit margin of the company).

First buildings built with the new system were semi-detached houses and row houses. The interior of apartments was left to be built when a client had chosen an apartment and selected the room layout, surface materials and fixed furniture. An installation subfloor system was used to allow flexible positioning of sewers. Later, the system was applied to the construction of apartment buildings, too. In this case, the whole building has to be finished on schedule. Thus, possibility to make changes to apartments is more limited as the construction proceeds. However, in Finland a general rule is that the majority of apartments have to be booked beforehand for a construction company to start actual construction of an apartment building. Therefore, most customers are able to take advantage of the possibility to customize their apartments with Kide-system.

2 BASIC PROPERTIES

As a basis for managing product data, a hierarchical model for building information was defined. Classifications were made for room types, product data items and grouping of product data items.

2.1 Room classification

An apartment was divided into 13 room types common in Finland. Combinations of product selections (styles) can be defined for each room type. In the database, a style definition contains tables for all room types.

Table 1. Room types

Code	Room
K1	Draught lobby
K2	Vestibule
K3	Lounge
K4	Kitchen
K5	Utility room
K6	Bathroom
K7	Toilet
K8	Shower
K9	Sauna
K10	Clothes room
K11	Living room
K12	Room in general (bedroom, workroom)
K13	Internal stairs

2.2 Global objects

General furniture and surfaces needed to model the interior of an apartment were specified as *global objects*. These objects are represented as parametric, geometrical objects within the CAD-software used (ArchiCAD). Global objects were designed as containers for product data.

Each global object is controlled with a script and groups of global objects are interactive. The spatial objects are a special group of global objects. They represent the surfaces of a room. Groups of other objects are dynamically interactive with spatial objects of the room they are positioned inside. For example, wall-related objects are automatically positioned according to the closest wall. Modifications to one object are inherited by other objects within the same room: for example, the height of toe-kick and cabinet worktop are related to each other to keep worktop upper surface level unchanged. This also affects installation height of wall cabinets and backsplash height to keep wall cabinets' and high cabinets' top surface at same level. Plumbing hook-ups, electrical switches and plugs are automatically positioned to correct height. They are also inserted together with appliances requiring electrical or plumbing connections.

2.3 Style definitions

The style definitions were created as database links connecting global objects' parameters to be defined with a link to a title in the database. A script is used to define relational conditions to determine which link should be used in case multiple entries could be linked with same parameter. For example, a primary link defining wall surface material class can be paint, tile, panel, glass or steel. A secondary link can be created for each material class. Depending on the primary selection, the correct secondary link is used. With this method, a preselected material can be defined for each material class when defining a style. In case the link is missing, a script is used to find a title from correct product category. Furthermore, each style defined item is verified and corrected if needed (See 2.9 Validation and verification). Style definitions can be saved directly from the BIM model with the integrated application, or edited with a browser-based interface.

Table 2. Global objects

Spatial objects	**Accessories**		**Cabinets**	**Cabinet accessories**
Floor surface	Window	Radiator	Base cabinet	Worktop
Wall surface	Door	Heat recovery unit	Wall cabinet	Sinks
Wall top surface	Threshold	Switchboard	High cabinet	Faucets
Ceiling surface	Lining	Sauna heater	Bathroom cabinet	Dishwasher valve
Fascia	Light, wall	Sauna benches	Mirror cabinet	Bidet hand shower
	Light, ceiling	Towel hook	Sliding door cabinet	End panel
	Switches	Toilet paper holder	Additional cabinet	Toe kick
	Wall plug	Wall surface area		Ventilation grill
	Floor drain	Shower cabinet		Backsplash
	Washer drain	Shower faucet		Filler
	Fireplace	Shower set		Under cabinet light
	Fireplace flue	Halogen light set		Hob
	Floor plate	Sauna light set		Toilet seat
	Ventilation vent, wall	Ventilation vent, ceiling		

The classification is an outcome of a pragmatic process of adding new classes for real products as needed. Therefore, the class hierarchy at present is still incomplete and not as logical and systematic as possible.

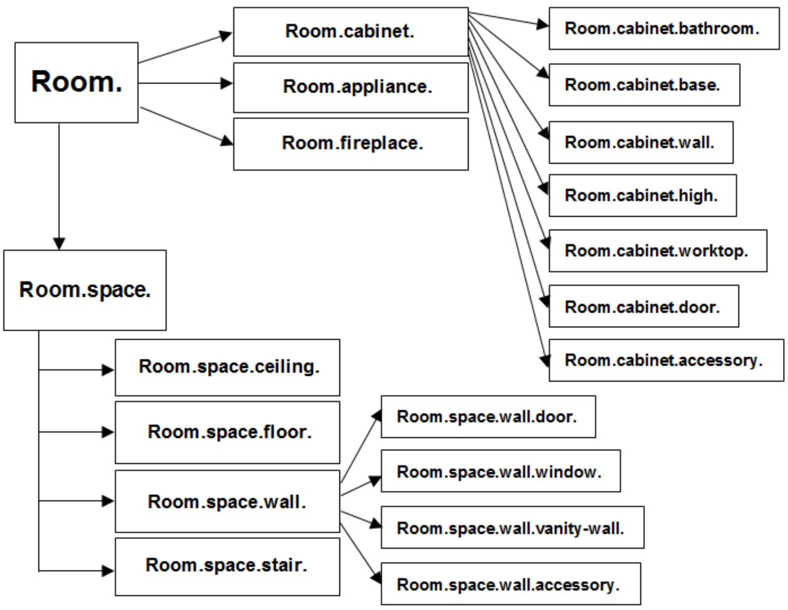


Figure 1. Classification of titles, main categories.

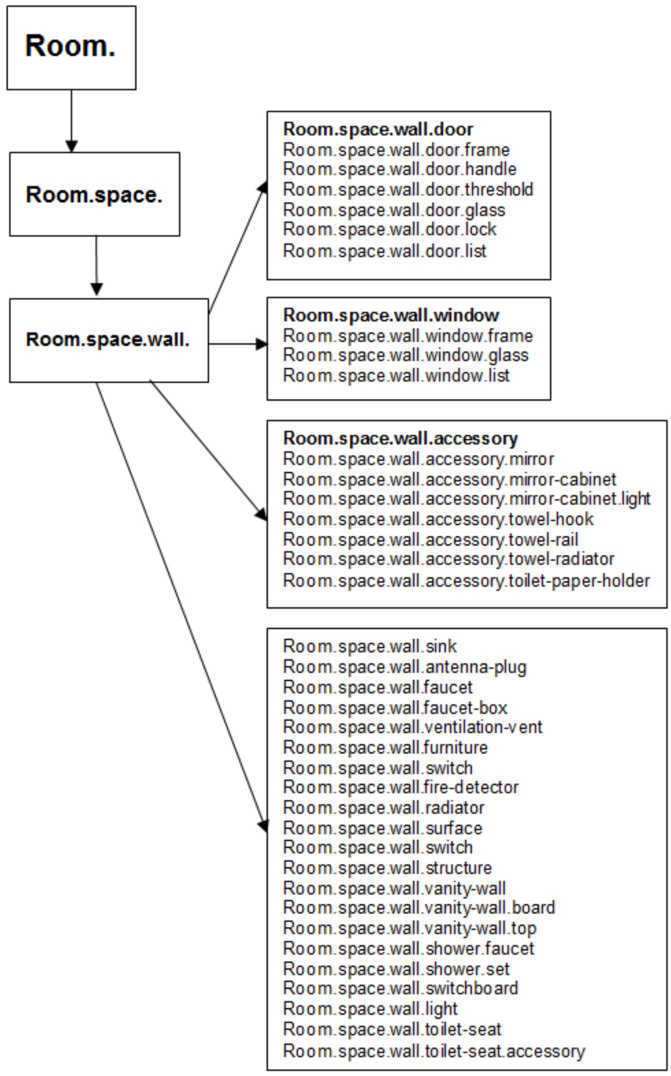


Figure 2. Classification of wall-related items.

Items related to walls are classified by their area of use. A category is defined for each product in database. Menu items in modeling software and style definition interface use category definitions to create selection lists. Global objects are parametrized with product data of corresponding category, including geometry and dimensional information for representation.

Based on the global object hierarchy, more detailed product data categories were created, defining an area of use for each title. Originally, each product title had a room category definition, too, but this was considered unnecessary and laborious to maintain.

2.4 Title definitions

Each item (title) in database contains a unique identification code, textual representation, classification category, pricing unit, purchase and selling price, supplier, period of validity, dimensions. Also colour, texture and 3-dimensional geometry for presentation are contained in the database, as well as any other information or documents like installation guides. Titles can also contain a relation and group definition. Relation includes one or more categories of child titles, whereas group definition is used to define groups of items from different categories.

2.5 Relation definitions

A typical relation definition connects master element with child elements. For example, a wall cabinet can have child elements like cabinet door, under-cabinet light, integrated cooker-hood and microwave oven, the category class of which can be defined with a relation definition.

2.6 Group definitions

In addition to the class hierarchy, we found out a need for a group definition. Instead of adding numerous new levels to class hierarchy, a group definition was used to define groups of elements in different categories. For example, a cabinet door type is usually available in certain colours only. The door type and colours available were given the same group definition, allowing an algorithm to be used to show valid choices and verify set values. Making the class hierarchy more complex would make user interface more difficult to use, and the database would have consisted of several duplicate items located in different categories. Group definitions can overlap, so different combinations of items in one category can be linked with several items in another category.

2.7 Leader titles

It turned out that major amount of titles were actually different kitchen cabinet doors, as each size of each door type has to be represented as a unique item. To make the list of kitchen furniture shorter and more useful in practice, each door type was defined with a leader title. A leader title is a general title belonging to a certain group of titles, and it has no size or price information. In our naming system, it was identified by adding ".leader" to the category name. When lists of elements in the BIM model are generated, cabinet doors are listed with corresponding leader title. Leader titles can be used to define styles, too, as the verification algorithm will transform leader title to correct unique titles based on dimensions and group definition of the element.

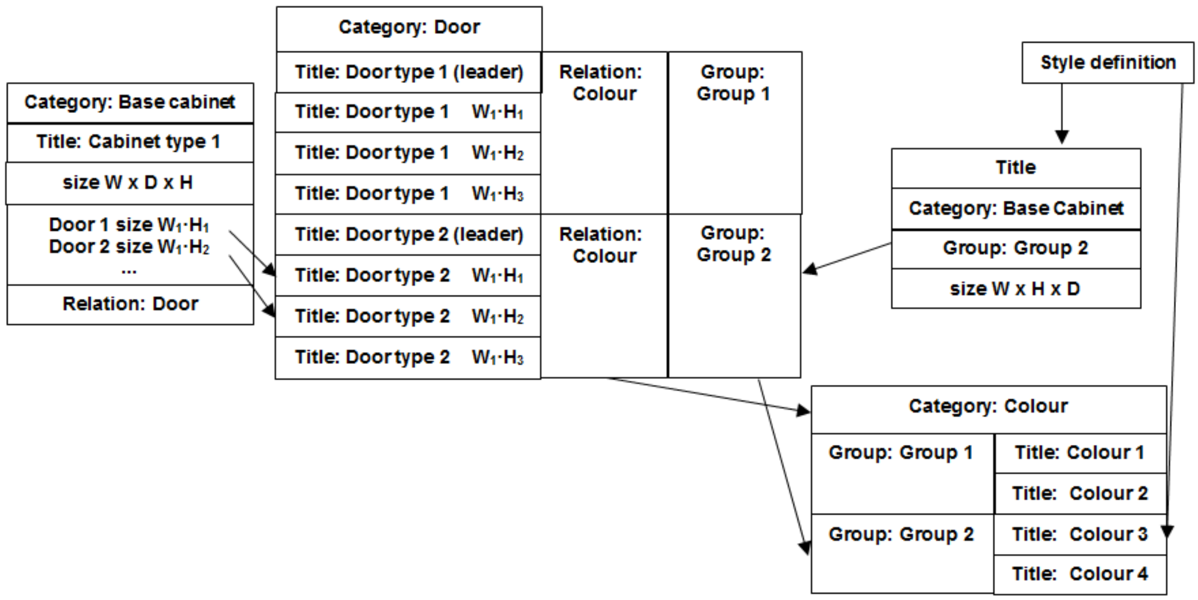


Figure 3. An example of relation and group definitions defining a valid title selection based on style definition.

The style definition sets a title with certain attributes. If the object parameters are contradictory, a best match is searched based on relation and group definitions.

2.8 Validation and verification

Users can modify the BIM model and data contained in it by making style selections, by changing single attributes with user interface menu selections, or by graphically editing the model. Any of these methods will change parameters of objects so that the title defined may be incompatible with other attributes of the element. A verification algorithm was created to check title definitions of elements.

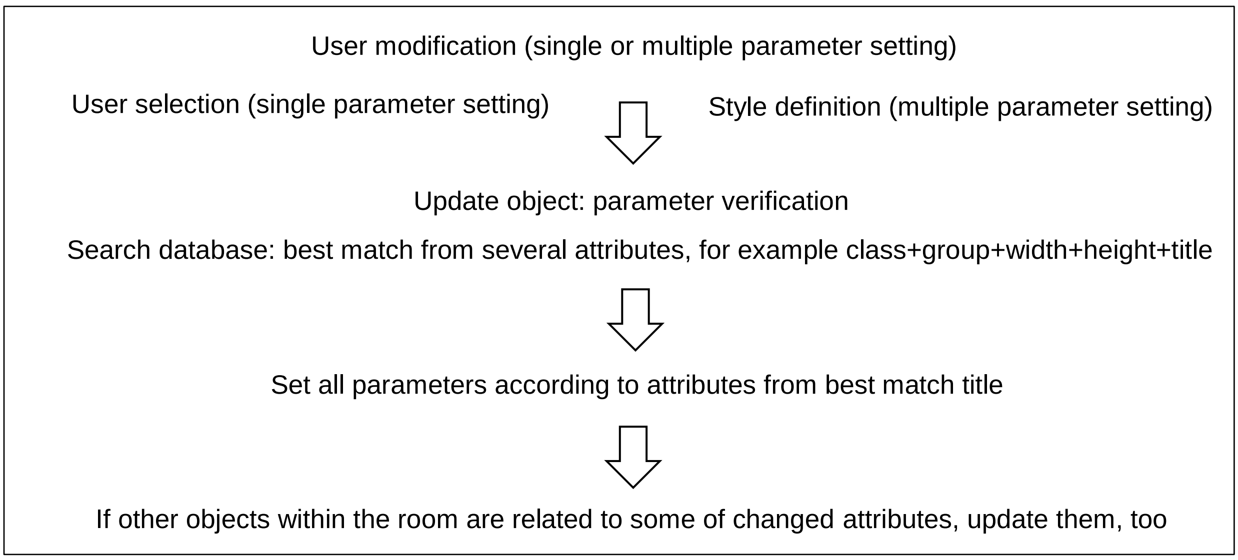


Figure 4. Verifying title definitions (product data embedded into the BIM model).

BIM model object parameters can be changed by style selection affecting all objects within a room; by making menu selections or by graphical editing of objects by the user. Modified parameters are verified from database with iterating rules.

2.9 Replace method

In the verification process, a flexible search for best matching replacement title was needed. In some cases, the groups of titles were inconsistent, and it was not possible to find a best match within a group. To cope with this situation, a replace method was introduced. When searching for the best match, alternative categories can be defined.

```
<search>category=[relation];height=[height];depth=[depth];group=[group:bestmatch:repla
ce(Group1|Group2):replace(Group3|Group4):replace(Group5|Group6)]</search>
```

Figure 4. An example of the script used to search titles in the database using replace method.
Search algorithm will search for a title with exact category, height and depth definitions, but with a group definition looking for a best match with possibility to replace the group with another group.

3 SUMMARY

This paper provides a compact description of the dilemmas encountered and solutions developed in a research and development project that has been going on for the past 10 years. The main observation might be that the real world needs and requirements are quite complex and require several methods of data management to tackle with. There is a continuous seek for balance between the ease of use and maintenance, and the need to define more complex classifications, relations and interactions to emulate and represent reality.

Product lifecycle Management in Wärtsilä – targeted advantages

Kimmo Tuominen[1], Kjell Norrgård[2],

[1]Product data management
Wärtsilä Finland Oy, Power Plants
Vaasa, 65101, Finland
kimmo.tuominen@wartsila.com

[2]Product data management
Wärtsilä Finland Oy, Power Plants
Vaasa, 65101, Finland
kjell.norrgard@wartsila.com

Abstract

This paper will explain Wärtsilä's journey in investing Product Data Management (PDM) system with target to share one source of data and information amongst the different organizations within Wärtsilä but also external design companies. Design reusability and traceability of product data are key factors for improving operational efficiency. Streamlining present work practices and improve operational efficiency via data quality and reliability are keys to successful PDM implementation.

The program will be gradually implemented in 3 phases which are split in the sub tracks and releases in order to ensure smooth deployment of way of working. Small improvement changes will be deployed into organization's day to day work.

The PDM program covers all Wärtsilä's businesses: Engine manufacturing, Services, Ship Power and Power Plants. Selling businesses - Ship Power and Power Plants are delivering solutions via Engineer to Order (ETO) projects. Services business is offering operational and maintenance to solutions in the field. This paper will focus on set targets and experiences of PDM development and implementation within Power Plants organization.

1 INTRODUCTION

Wärtsilä is investing in the PDM program in order to improve visibility and collaboration between its businesses. Evaluation of possibilities and selection of PDM software provider started in 2004. The PDM program was decided to divide in different phases.

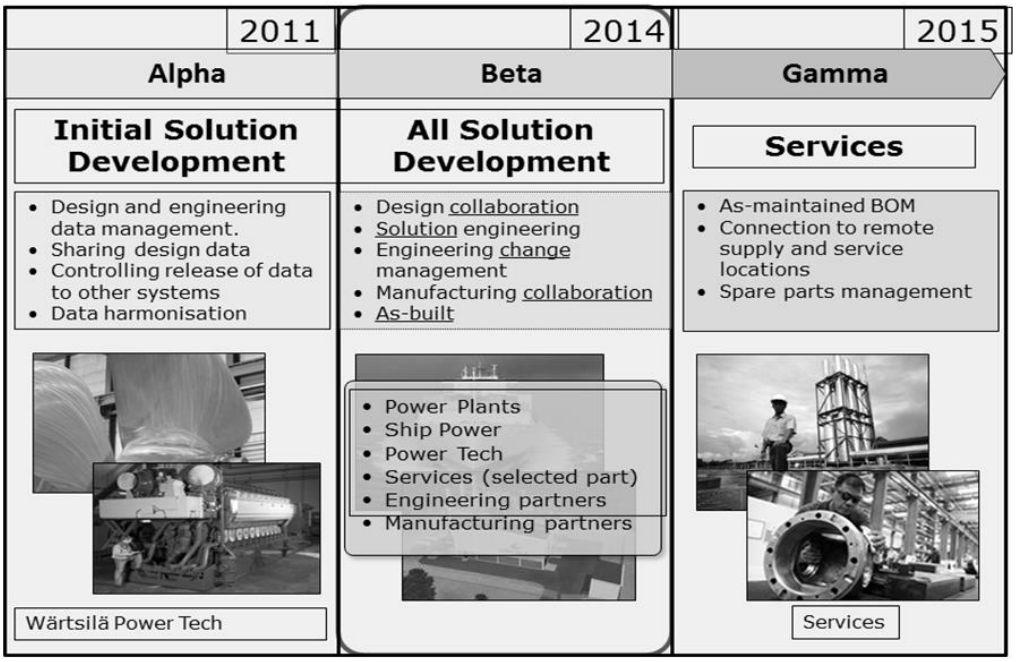


Figure 1. Illustration of PDM program phases.

First phase project (alpha) started in 2007 and it considered the engine manufacturing business Power Tech's design and manufacturing processes. Siemens PLM software called Teamcenter was the chosen software during alpha phase.

The second phase project (beta) was started in 2010. The planning of beta project was run parallel with implementation and deployment of alpha project until the alpha project was deployed and closed in 2012. The beta project was enlarging the PDM program to consider selling business (Power Plants, Ship Power and Services) and their design, product development, procurement and delivery processes of solutions to end customer. The beta project is under progress at the moment. The third phase project (gamma) has not been started but it is planned to start after beta project implementation. The content of gamma is considering Services business' operations and maintenance of installed solutions and products in the field. The PDM program is steered by cross divisional steering committee.

This paper will describe the PDM beta project from Power Plants perspective. Project's set targets and experiences, challenges that global, complex and cross divisional PDM project implementation has faced. Since the project is ongoing we cannot report yet if the targets are or will be met. This paper gives instead the illustration of what is planned for PDM beta implementation in order to meet the set targets.

2 PRODUCT DATA MANAGEMENT PROJECT IN WÄRTSILÄ POWER PLANTS BUSINESS

The PDM beta project in Wärtsilä Power Plants started with establishing a dedicated PDM development team with 6 development engineers and the project manager. External consultants were used describing the "as is"- situation regarding information and data flows over the departments needed for power plant's solution delivery. External consultant expertise was used to define the proposal for "to be"- scenario for getting the idea of the concept to be developed for the beta project.

2.1 Initial phase of the project

Before the PDM development team was formed all the business units' managements and selected experts were interviewed for collecting high level management expectations about the PDM beta projects' outcome.

Table 1. The list of high level requirements.

Requirement	
R1	Enhance the lifecycle view on product information
R2	Emphasise usage of pre-designed modules
R3	Manage functionality based design
R4	Increase the amount of sales projects
R5	Enforce an information flow that supports concurrent engineering
R6	Put focus on entire solutions, not only single products
R7	Fast and reliable tools to support designers globally
R8	Reduce lead time to market for new products to faster gain profit
R9	Efficient collaboration with external partners
R10	Capture and develop knowledge for managing full solution projects
R11	Utilize knowledge to strengthen Wärtsilä's position
R12	Improve the quality of design
R13	More controlled handling of proposed changes to design
R14	Better availability of calculation and validation results
R15	Focus on total product lifecycle offering in sales
R16	Improve efficiency with global processes and applications
R17	Decision-making close to customers
R18	Better planning of product development tasks
R19	Product Data Management must support a global design organisation
R20	Enable flexibility in the choice of production location
R21	As-built information should be available
R22	Enlarge the service scope
R23	Closer integration of Ship Design
R24	Handle complexity of global design
R25	Clear product ownership
R26	Focus on product lifecycle profitability
R27	Reduce the number of existing materials

The advantages set and expected from the PDM beta project from Power Plants business were derived from its business strategy and were focusing on streamlining and improving the way of working. During the initial phase of the PDM beta project it came essential that the expectations were not only limited to traditional Product data management but extended to the field of Product lifecycle management (PLM).

2.2 PDM vision for Power Plants business

Understanding the needs for the PDM beta project among the PDM project team and communicating the project's objectives further to the Power Plant organization the vision statement for PDM project was created based on high level requirements:

"PDM improves efficiency of Power Plants' operations and enables business growth by improved collaboration and accessibility to common structured product data and simplified work flows via user friendly system."

2.3 User survey, goals and benefits

Before the planning phase of the PDM beta project we concluded a user survey among the Power plant organization. The Purpose of the survey was to measure how power plant employees, sales force, designers, project people feel the situation with product data and information in their every day work. The result showed that trustworthiness of the product data and information is in between 80 -90 % within Power plants. All efforts to search, check and correct data, information or revisions will take too much of employees working time. This is creating frustration among the organization since this not the effective work time. From high level requirements and the result of survey the targeted goals and benefits were categorized for financial performance, time reduction, quality improvement and business improvement. Detailed goals and benefits are shown in table 2.

Table 2. Targeted goals and benefits.

Financial Performance
- Increased revenue from earlier market introduction of products
- Reduced product development costs

Time Reduction
- Reduce project lead time
- Reduce engineering change time

Quality Improvement
- Enhance project management (engineering) process
- Reduce the amount of warranty costs
- Reduce the number of customer complaints

Business Improvement
- Increase in the innovation rate,
- Increase reuse factor for design and parts
- Increase product traceability,
- Ensure 100% configuration conformity

2.4 Planning phase of the project

In the project's planning phase the first was defined the conceptual specification of what needs to be accomplished. In order to develop PDM project concept the Quality Functional Deployment (QFD) method by all business divisions was used. The QFD method is a working methodology for finding how the business values, requirements, work processes and system software architecture will be connected together, making sure that expected advantages were included in PDM concept. It also helped to determining the project sub tracks for smaller release tracks.

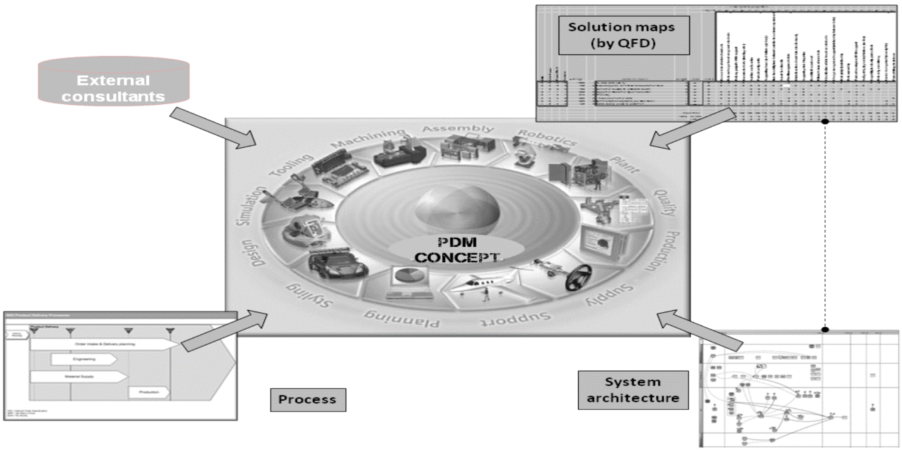


Figure 2. Product data management concept work model.

All the businesses are having their own strategies and business processes describing how their businesses are run. These processes were not enough to fulfill the requirements of lifecycle aspects of the common product with engine manufacturing and especially support after sales activities of Services business. Sometimes power plant projects are extension projects where an existing power plant is enlarged with a number of new engines to fulfill customers increased electrical capacity requirements. The information in the beginning of the project is essential to know how the product is maintained during its operation. This knowledge will give advantage for starting the solution design adaptation to existing power plant in the field. The PDM concept consists of product data model based on ISO 81346 standard. During the conceptual development of the beta project it was notified that implementing PLM functionalities we also need to develop common Wärtsilä PLM process. A subproject to develop PLM process was initiated.

2.5 Wärtsilä PLM process

A cross divisional team between all business was establish to describe a Wärtsilä PLM process which is common for all businesses and it is interrelated with each businesses' business process. In the PLM process was discovered three different scenarios:

1. Solution and product development
2. Solution concept and product portfolio lifecycle
3. Customer solution and product delivery

Solution and product development life cycle is focusing on the internal development projects for developing suitable solution and product designs based on business strategy and market requirements for reusing in customer solution and product delivery process. The reusability of design or even further material and supplier definitions will drastically shorten the customer solution delivery times because the design and supply chain is prepared for certain level. Sometimes this is called product standardization. This covers all business' solution and product development projects.

Solution and concept portfolio life cycle focuses on portfolio management. Design portfolio, product portfolio management for each business and portfolio ownerships separately. Each business has their own development projects for designs and products. Engine manufacturing is developing common designs for engine products for selling businesses, Ship Power and Power Plants, to be used in their product portfolios for offering and customer delivery projects. The sales portfolio lifecycle process is managing the product introduction and making it available for sales and also expiring from sales.

Customer solution and product delivery life cycle is focusing on the solution and products offered, sold and delivered, based on specific customer requirements. These are the operational projects. In order to fulfill customer requirements and offer an optimal solution based on his requirements demands first understanding the customer requirements but also translating the requirement for specific available reusable design in order to gain the operational efficiency during delivery project. Therefore it is essential to have good understanding of the requirements and design maturity for developed products and solutions in sales product portfolio. The solution and product design and product instances' life cycles are kept up to date during the selling businesses delivery projects and during warranty period. The full visibility of the solution and product instances maturity states and design histories are known when solution responsibility is transferred to Services business for the maintenance period.

2.6 Wärtsilä PLM concept

PLM concept developed during the planning phase includes Wärtsilä product data model based ISO 81846 step standard. The standard describes the product's different design aspects: functional, component and product design as well as instance design and specification for physical parts. This is enabling connection of initial product requirements to different product's evolution states in its life cycle, design, delivery and operational and maintenance phases until decommissioning of the product. The Wärtsilä product life cycle concept comprises the evolution of product from requirement to ready installed and maintained product as described above, and traceability backwards from the replacement of parts during service to design changes and even requirement changes over the lifetime of product.

The PLM concept includes the tools from Customer Relationship Management (CRM), sales offering, Computer-Aided Design (CAD), PLM and Enterprise Resource Planning (ERP). See the concept below in figure 3.

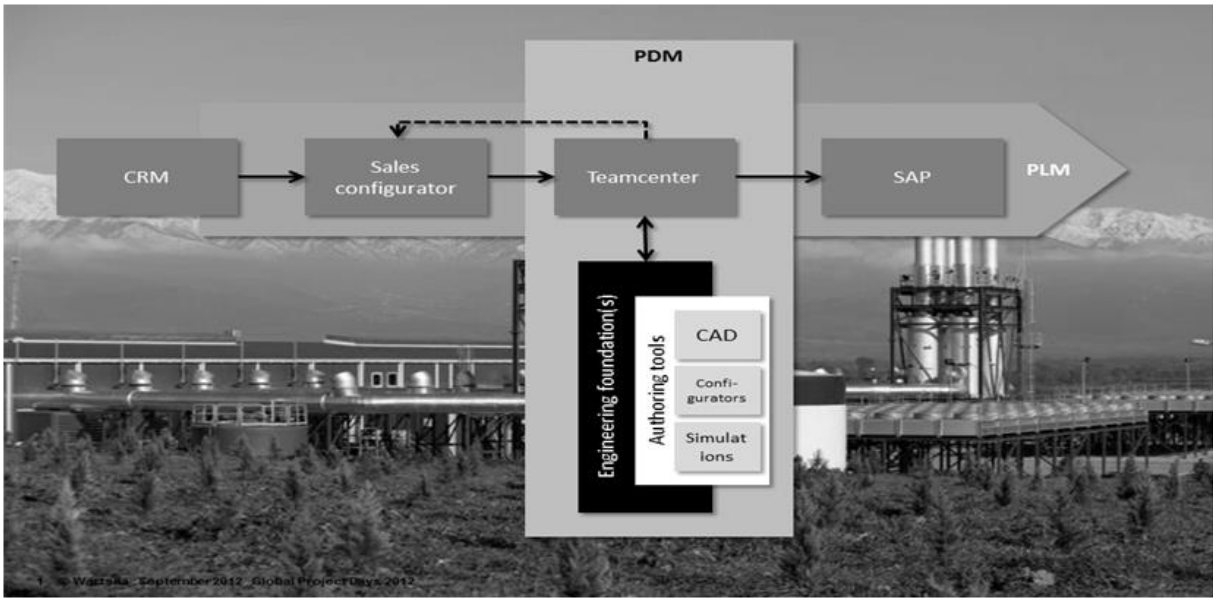


Figure 3. Software architecture and data flows of Wärtsilä PLM concept.

Lately this has led us to investigate how to manage PLM functionalities. Should PLM functionalities be separated from PDM and Teamcenter. Would it be worthwhile to build another hub over the PDM to handle PLM functionalities? This study is ongoing at the moment.

2.7 PDM beta project state at present

Presently the sub track 1 of PDM beta project is in execution phase and functional testing has been performed. The sub track 1 consists of data flow from sales tools (CRM and Sales configurator) to Teamcenter and further downstream to SAP for project budgeting and work breakdown structure (WBS). Next step is to built the work flows for sub track release 1 and continue with testing of workflows during March. Release and deployment of first sub track is planned to take place 20th of May.

Same time the PDM beta project's sub track 2 is in planning phase. The sub track 2 is focusing on engineering activities, engineering change management and engineering tool interconnections. The project team is presently defining functionalities for second sub track. The sub track 2 planning approval is scheduled to be end of March.

3 EXPERIENCE AND CHALLENGES

The Wärtsilä PDM program started by implementing functionalities defined in the alpha phase. The requirements specified for the alpha project by engine manufacturing business Power Tech. Once the new beta project was involved the complexity of the total project increased. The PDM beta project targets were somewhat different from alpha project's targets. Agreeing of new requirements and common Wärtsilä beta concept was a challenge within the cross divisional project organization. Alpha was implemented in production environment and no changes or improvement were allowed first since Power Tech had deployed alpha and the organization was just trained for new way of working. This has caused delay in the beta project schedule. Both of the projects alpha and beta are lead by project manager from Information Management (IM) department. The project is an operational development project and improvement targets related to businesses and impact on businesses. The project manager's acceptance or readiness to escalate change requests to steering committee was seen challenging. Overall PLM development is abstract and very complex which has created challenges to communicate the project internally. The PDM project owner is the group vice president of Power Plant business and his support and understanding has been key factor to take to project forward.

4 SUMMARY

The management's role, PDM project owner's and steering committee's members' roles are key to the success of the project. They have to support fully the project team with the complex project. At Power Plants the project owner has had active and supportive role with the Power Plants PDM team. Sequenced meetings with project owner have been held and these had been fruitful meetings in sharing targets and understanding the project objectives.
The smooth progress of the project requires all businesses good understanding and commitment to common objectives and targets. Now looking back at the whole Wärtsilä PDM program, more emphasis for clear understanding and committing the cross divisional PDM team to the common target should have been in focus. When creating the project schedule more time should have been reserved for the initial activities, for creating, sharing, agreeing and understanding the common targets within all businesses. The later the discrepancies in targets and goals agreements go, the more difficult it is to agree. This will cause delays in the project and can jeopardize the whole project‘s progress. All shareholders from all businesses should have been involved from the beginning at least for setting and agreeing the goals and targets for whole PDM program.

The overall progress of the PDM beta project could have been better if the targets and goals and would have been clearly agreed and committed in the beginning of alpha project within all businesses. The PDM project proceeds in Wärtsilä and Power Plant's business as planned. There is expected to be unknown challenges on the journey going forward with this complex PDM program. However the objectives to reach the target remain.

The Module System and its requirements for PDM/PLM systems

Jarkko Pakkanen[1], Jouni Lehtinen[2], Tero Juuti[1] and Timo Lehtonen[1]

[1]Department of Production Engineering
Tampere University of Technology
Tampere, 33101, Finland
(forename.surname)@tut.fi

[2]MacGregor, Dry Cargo
Cargotec
Kaarina, 20780, Finland
Jouni.Lehtinen@cargotec.com

Abstract

This paper presents main elements of the Module System and discusses the needs these elements set for information technology (IT) support systems such as product data management (PDM) and product life cycle management (PLM) systems. Enabler of the Module System is standardisation and the purpose is to gain more profit to the company by re-use and repetitions in order-delivery processes and to facilitate responding to changing market needs. Approach suggests that the Module System consists of partitioning logic (design rationale of the module division), modules (building blocks of product variants), interfaces (enabler of interchangeability of the modules), architecture (layout of modules and their interfaces) and configuration knowledge (compatibility rules and constraints of modules). The paper emphasises that these elements and their relations should be able to be managed in IT support systems. Findings are based on a shipbuilding industry case in which the fit of the Module System for PDM/PLM system of a company was discussed. Practical implications propose the five design elements that must be considered in designing modular products and explain the issues in managing of modular products by PDM/PLM systems. The categorisation of the Module System to five areas presented is a novelty.

1 INTRODUCTION

Modularisation has been presented as a technique for responding to quickly changing customer requirements causing the need for product variety [1-2]. According to [3], product variety explains the range of products the company can offer within a particular period of time in response to market demand. The aim of the modularisation is to create variety from the customer's viewpoint, while at the same time to show commonality between module variants and other properties that reduces complexity in the operations of the company [4]. There are several definitions often discussed with modularisation such as modularity and modules. Modularity is a property of modularisation activity and it can be categorized according to its reasoning. Besides modularity aiming at configuration of the products and managing the product variety, there can be modularity in which variation of the products is not needed. This is understood as a life cycle modularity in which the division of the product into modules is based on the reasons for instance in manufacturing, assembly, logistics and service [5]. This paper considers modularity aiming at configuration. Modules are building blocks of modular products having defined interfaces according to [4-6]. Interface enables the independence and the interchangeability of the module [5] and thus it can be understood as a meeting point or area where two or more modules are connected or related to each other.

As discussed, configuration is a topic close to modularisation. Configuration is an activity where a product variant (synonyms: a product instance, a product configuration) that is part of a product family is defined [7]. Product family is a group of products which share common properties, parts, sub-systems and can fulfill a set of market needs [8]. Product families benefit of modular structures by re-use and repetitions in sales-delivery process [7, 9]. The design challenge is to define which elements of the product are standard, configurable, partly configurable or delivery specific [9]. Configurable element consists of alternative standard elements which are interchangeable modules responding to a certain need [9]. Partly configurable product structure is combination of standard, configurable and delivery specific elements [9] Configurators are considered as facilitators of a product configuration task [10-12]. The task of the configurator is to define a product variant based on the configuration model that considers compatibility rules of customer needs and product elements [10]. Configurators are usually related especially on the sales and engineering functions of the company. Other IT support systems are needed besides sales or engineering configurators relative to the product life cycle that considers all the phases from the defining of business objectives to the disposal or recycling of the product.

It has been presented by [12] that the amount and quality of information in the design environment has become vast and geographical location of stakeholders of the information is wide spread in several industries. Information technology (IT) support systems have been introduced to this issue. Product data management (PDM) systems provide access to and control of information and support a set of processes and functions related to the information and enables integration of different systems according to [12]. From user viewpoint, functions consider management of data vault and documents, workflow and processes, product structure, classification and programs/projects [12]. According to [12], modern PDM aims to manage product data considering the whole product life cycle but product life cycle management (PLM) systems are discussed also separately in the literature. Product variants have been recognised as an important parameter influencing complexity regarding IT support systems such as PDM [12]. In this paper, the focus is in the relation between the Module System and PDM/PLM systems. The important design elements in modularisation and their relations and information content are discussed. The fit of the information content of the Module System to PDM/PLM is analysed using a case. This paper has thus three research questions (RQ):

RQ1: How can the Module System be defined?
RQ2: How can information related to the Module System be defined?
RQ3: What kind of requirements does the information related to the Module System set for PDM/PLM systems?

The structure of the paper is following. At first in Chapter 2, the elements of the Module System are defined and what kind of information is related to the elements of the Module System is discussed. Chapter 3 focuses on and how modular products are considered in IT support systems. The results are gathered and discussed in Chapter 4. Conclusions are presented in Chapter 5.

2 THE ELEMENTS OF MODULE SYSTEM

As already discussed in the introduction, there are several aspects related to modularisation of the products. A summary about important elements regarding modularity and configurable products, highlighting the separation of design process, order-delivery process and management elements based on the publications by [5,7,13], has been made by [9]. This is presented in Figure 1. Of this figure, the important elements of the Module System can be analysed. Figure 1 explains that customisation strategy considers customisation principles and policy meaning that who can customise in certain life phase and what kind of variability is enabled in certain life phase. These elements have to be taken into account in the configuring process. The main elements of the Module System are **architecture**, **modules** and **configuration knowledge** as shown in Figure 1. It is explained that the technology enables modules and these modules enable certain architecture. Figure 1 represents that configuration knowledge includes information about interchangeability rules and constraints. From the design process perspective, these three elements are important in the designing of Module System but of these elements, other critical elements in developing of the Module System can be further on derived. **Interfaces** are explained to partly define modules and their interdependency and how modules can be partitioned. **Partitioning logic** has been explained to affect directly on the partitioning of the product elements and thus it has an effect on the product architecture and interfaces as shown in Figure 1.

Partitioning logic is guided by customisation tactics which considers how variability can be enabled for instance by using configurable or modular structures as presented in Figure 1.

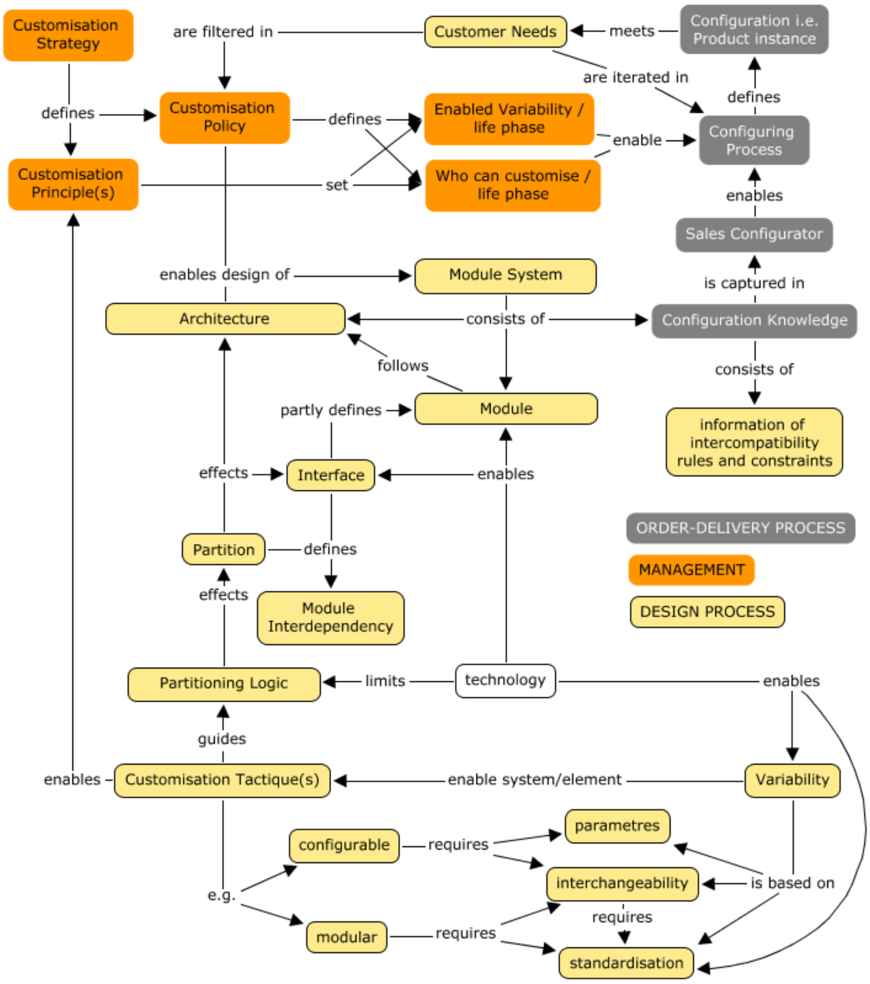


Figure 1. Summary of the configurable product key concepts and their relations [9].

Based on the summary made by [9], we discuss that the Module System consist of partitioning logic, modules, interfaces, architecture and configuration knowledge. The summary of the definitions of these elements is given in the following:

- **Partitioning logic**: reasoning leading to a certain module division
- **Modules**: building blocks of the Module System
- **Interfaces**: enablers of interdependency and interchangeability of the modules
- **Architecture**: layout definition of the structure of Module System defining how modules and their interfaces are located in the product
- **Configuration knowledge**: compatibility and constraints of the modules and customer needs

What kind of information is related to these five elements? **Partitioning logic** considers reasoning about the product structure thus including statements regarding the module division. It has been stated by [5] that it is beneficial if the development process of a modular product starts with setting the objectives from business and customer context and ends with validation in which it is ensured that the result of development fulfils the expectations and requirements. Objectives for developing of modular product can be both qualitative and quantitative and they can be for instance linked on different steps of the product life cycle. Information regarding to validation can be based for example on estimation of business impact analysis of modular product considering product life cycle phases. Partitioning logic considers also more technically the partitioning of the product on different kind of elements. As discussed by [9], there can be standard, configurable (modular), partly configurable and unique elements in the product. Consequently, partitioning logic should explain the reasoning of why elements are certain type and in the case of modular products to which elements of the product there is a need for variants and why. It is discussed in [14] that it is important to understand how the need for variety arises from the processes in which the customer uses the products. As suggested in [5] and [14], designing of **modules** proceeds from defining of preliminary/generic modules to designing of definitive/detailed modules. At first the modules can be understood as module candidates and later on in the development when the need for variety is understood better they should be designed with detail. Also different module versions have to be considered because of possible technological evolution. Product and feature roadmaps have been presented to this issue [9]. **Interfaces** concerning mechanical structures are discussed typically quite abstractly in the academic publications of modularization. Often discussed interface definitions consider for instance electrical devices such as the example presented in [3]. There are limited numbers of research disciplines in which more precise suggestions concerning the definition of interfaces can be found. In Systems Engineering [15], agreement concerning the interfaces between two or more modules is made. This agreement, often named interface control drawing or interface control document, considers for instance requirements set by the environment around the modules (e.g. free space), accessibility (e.g. service), type and number of connectors, mechanical properties or parameters related to the energy for instance. Modules, interactions and interfaces are defined in modular **architecture** according to [4]. There are closed and open modular architectures [6]. In closed architecture, all the possible modules and combinations are defined. In open architecture the situation is the opposite: interfaces are defined but there is no definition of all the possible modules and their combinations. Under the circumstances, architecture considers technical compatibility of the modules in a level which has also a role in defining of the configuration knowledge. Representation of **configuration knowledge** as a separate description until it is implemented to the product configurator has been found out advantageous in several cases [11]. There are approaches [16-17] in which matrixes are used for defining of configuration knowledge. There are also multiple other techniques in which for instance Unified Modeling Language (UML) is used in describing the configuration knowledge [18]. In high level, the aim is the same in these different approaches; to explain the possible combinations in relation to the requirements such as customer needs and the modules.

3 THE COMPATIBILITY OF MODULE SYSTEM FOR PDM/PLM SYSTEMS

In this chapter, the fit of Module System on the PDM/PLM is analysed using a case. The presumption is that the Module System consists of the information content as shown in Table 1 based on the issues discussed in the earlier chapter. The case company operates in shipbuilding industry and provides integrated cargo handling solutions for merchant marine segment. Shipbuilding can be described as engineered-to-order type of industry which, despite not completely unfamiliar with principles of modularity, hasn’t traditionally applied modular product architectures in an extensive manner. Recently, new product architectures exploiting modularity have been developed by the case company. Simultaneously there has been a target to implement new PDM/PLM tools to support new way of working.

Table 1. The Module System elements and the information content of the each element.

Module System elements	**Information content**
Partitioning logic	• objectives related to the life cycle phases of the product • element types of the product (standard, fully configurable, partly configurable, unique) • reasoning for the need of variety (customer/ market context) • business impact analysis of the module system
Modules	• hierarchic list and sketches/drawings of preliminary/generic modules • hierarchic list and sketches/drawings of each definitive module • versions
Interfaces	• agreements or definitions of interfaces between two or more modules
Architecture	• preliminary architecture/layout with preliminary/generic modules and their interfaces • definitive architectures/layouts with definitive modules and their interfaces
Configuration knowledge	• preliminary and definitive technical compatibility of the modules • compatibility of customer needs • preliminary and definitive compatibility of the customer needs and the modules

Partitioning logic of the Module System is traditionally not identified as PDM/PLM issue but merely a challenge of development work. Typically the partitioning logic of modular system is not documented at all or the data is here and there in different documents and reports. With basic function of connecting files to items the partitioning logic could be made more visible; however it is not clear what would be the real benefit of it. At present, major PDM/PLM software don't offer any relevant tools for defining e.g. module division for new products. This is not surprise as definition of suitable partitioning methods remains challenge even for scholars. Management of **modules** and **interfaces** in PDM/PLM systems is commonly applied with item structures, related attributes and supported file formats. The major challenge for the case company has been the integration of CAD and PDM/PLM systems. The available integration capabilities with simple check-in check-out functions might be efficient enough for assembled-to-order businesses, however available CAD integrations are often inefficient in case there's need to create and modify several customer specific modules in a short period of time. Regarding the interfaces, there seems to be no defined, task specific, functions available in PDM/PLM systems. However, interfaces can be defined and managed with existing item based structures and related functions. At the moment, the management of interfaces in PDM/PLM systems as separate to modules is not seen relevant in industrial companies. **Architectures** and related **configuration knowledge** are specified by documents which are again linked to item structures. In addition, leading PDM/PLM software does provide tools for configuration of modular architectures with simple rules. This means ability to create rules for selecting and combining pre-defined options (items). Such functionality is typically feasible for product architectures that have very standardized modules. However at the moment the major PDM/PLM systems don't support any simple means for modification of the selected modules and especially CAD objects (e.g. transfer of engineering design parameters). Furthermore, there's a lack of functions for even simplest calculations to support configuration logic. This creates significant challenges in industrial applications that feature open product architecture. Lack of standard functions leads into complex integration of PDM/PLM and configuration software or CAD via third party software.

4 RESULTS AND DISCUSSION

In this section, answers to each research questions are given and discussed. RQ1 was: “How can the Module System be defined?” Main elements of the Module System are summarised in Table 1. The elements of the Module System consist of partitioning logic, modules, interfaces, architecture and configuration knowledge. In modularisation aiming at configuration, all the elements need to be considered in the development of the Module System. RQ2 was: “How can information related to the Module System be defined?” Column ‘Information content’ in Table 1 explains what kind of information is related to the Module System. Information includes reasoning of the Module System, definition of the modules and their interfaces, definition of the architecture and layout including how modules are located in the product and the knowledge about compatible modules, thus definition of possible product variants. RQ3 was: “What kind of requirements does the information related to the Module System set for PDM/PLM systems?” Information content summarised in Table 1 has relations to each other. In order to manage the development of a modular product, there has to be case specific understanding about relations of information content and this should be supported by IT systems. The experiences within the case company reveals that Module System and related information can be managed without any significant challenges if the modular architecture is closed and the configuration is made in module level which in PDM/PLM software means selection of suitable combination of items. In turn, modular products with open architecture are still not supported with mainstream a PDM/PLM application and there are limitations considering the linking of the partitioning logic and configuration knowledge of the modules to PDM/PLM systems for instance.

5 CONCLUSIONS

In this paper a novel approach to the definition of Module System was discussed. Five elements consisting of partitioning logic, modules, interfaces, architecture and configuration knowledge should be considered in developing of a modular product family. To these five elements, different kinds of information are related. This information should be able to be managed using IT systems such as PDM/PLM to facilitate operations in the companies. The ability to store and to use the information related to the Module System by PDM/PLM systems was seen possible for the most part on the basis of a case. The challenges are related for instance to the definition of the partitioning logic of the module division and the configuration logic. The former can become important in order to understand the existing Module System in a situation when modifications to the Module System are needed to be done. The latter justifies the existence of separate product configurators. In order to reduce the need for complex software integrations, a need for a single application to handle the situation exists.

References

[1] Pine, B. J. Mass Customization – The New Frontier in Business Competition. Harvard Business School Press, 1993. 368 p.

[2] Victor, B. & Boynton, A. C. Invented Here - Maximizing Your Organization's Internal Growth and Profitability. Harvard Business School Press, 1998. 272 p.

[3] Ulrich, K. and Eppinger, S. Product Design and Development. 4th edition. McGraw-Hill. 2008. 384 p.

[4] Andreasen, M. M. 45 Years with design methodology. Journal of Engineering Design. 2011. Volume 22, Issue 5. Pp. 293-332.

[5] Lehtonen, T. Designing Modular Product Architecture in the New Product Development. Dissertation. Publication 713. Tampere University of Technology. Tampere. 2007. 220 p.

[6] Fujimoto, T. Competing to be really, really good – The behind-the-scenes drama of capability building competition in the automobile industry. International House of Japan. 2007. 156 p.

[7] Pulkkinen, A. Product Configuration in Projecting Company: The Meeting of Configurable Product Families and Sales-Delivery Process. Dissertation. Publication 712. Tampere University of Technology. Tampere. 2007. 184 p.

[8] *Simpson T. W., Maier J. R. A. & Mistree F. Product platform design: method and application. Research in Engineering Design. 2001. Volume 13, Issue 1. Pp. 2-22.*

[9] *Juuti, T. Design Management of Products with Variability and Commonality - Contribution to the Design Science by elaborating the fit needed between Product Structure, Design Process, Design Goals, and Design Organisation for Improved R&D Efficiency. Dissertation. Publication 789. Tampere University of Technology. Tampere. 2008. 155 p.*

[10] *Soininen, T. An Approach to Knowledge Representation and Reasoning for Product Configuration Tasks. Dissertation. Acta Polytechnica Scandinavica. Mathematics and Computing Series. No. 111. Helsinki University of Technology. Espoo. 2000.*

[11] *Haug, A., Hvam, L. & Mortensen, N.H. Definition and evaluation of product configurator development strategies. Computers in Industry. 2012. Volume 63, Issue 5. Pp. 471-481.*

[12] *Crnkovic, I., Asklund, U. & Persson Dahlqvist, A. Implementing and Integrating Product Data Management and Software Configuration Management. Artech House Publishers. 2003. 338 p.*

[13] *Tiihonen, J., Lehtonen, T., Soininen, T., Pulkkinen, A., Sulonen, R. & Riitahuhta, A. Modelling Configurable Product Families. Proceedings of the 12th International Conference on Engineering Design, ICED99. 1999. Volume 2. Munich, Germany, 24.-26.08.1999.*

[14] *Lehtonen, T., Pakkanen, J., Järvenpää, J., Lanz, M. & Tuokko, R. A Brownfield Process for Developing of Product Families. Proceedings of International Conference on Engineering Design, ICED11. 2011. Technical University of Denmark, 15.-18.08.2011.*

[15] *Stevens, R., Brook, P., Jackson, K. & Arnold, S. Systems Engineering - Coping with Complexity. Prentice Hall. 1998. 374 p.*

[16] *Bongulielmi, L. Die Konfigurations- & Verträglichkeitsmatrix als Beitrag zur Darstellung konfigurationsrelevanter Aspekte im Produktentstehungsprozess. Zentrum fur Produktenwicklung. Dissertation. VDI Reihe 16, Nr. 151. ETH. Zurich. 2003. 218 p.*

[17] *Nummela, J. Integrated Configuration Knowledge Management by Configuration Matrices – A Framework for Representing Configuration Knowledge. Dissertation. Publication 589. Tampere University of Technology. Tampere. 2006. 205 p.*

[18] *Felfernig, A., Friedrich, G., Jannach, D. & Zanker, M. Configuration Knowledge Representation using UML/OCL. Lecture Notes in Computer Science. 2002. Volume 2460. Pp. 49-62.*

The role of Product Data Management (PDM) in engineering design and the key differences between PDM and Product Lifecycle Management (PLM)

Merja Huhtala[1], Mika Lohtander[2], and Juha Varis[3]

[1, 2, 3] Mechanical Engineering
Lappeenranta University of Technology
Lappeenranta, 53850, Finland
merja.huhtala@lut.fi
mika.lohtander@lut.fi
juha.varis@lut.fi

Abstract

This paper will take a closer look at PDM (Product Data Management) which is one of the most important systems in today's industry. Every day designers produce huge amounts of information, including drawings and related datasheets. This information has to be saved in a specific place where it is easy to find and modify. To facilitate this, PLM (Product Lifecycle Management) has increased its benefit to companies. Spare part selling has become an important factor for companies. In the case of spare parts, it is important that the PDM is working as it should; without a correct PDM the PLM does not work and tracking of an old product may even be impossible. This also increases the difficulty of selling spare parts. Knowing how the PDM system should work and what kind of information is possible to add to the system are the key elements for success.

1 INTRODUCTION

PDM (Product Data Management) is not actually software; therefore it should be called a system. This system handles the created information during the designing process. PDM is nowadays the most important software in the industry, along with PLM (Product Lifecycle Management). These two terms are commonly used synonymously although they are two different systems. It is hard to say where the distinct line between these two systems lies and even in some cases PDM is used in a similar manner to PLM. However, normally PLM focuses on the whole lifecycle of a product and PDM is a storage location for all the information that is related to the product. Because of this confusion of the terms the actual information concerning only the PDM seems to be hard to find, or in fact hard to differentiate from PLM information. [1]

The history of PDM started in the early 1980s. Because of the lack of computers, PDM was operated manually and designers managed the drawings and data sheets by hand. After the escalating access to computers and designing programs, PDM was linked to these designing systems (CAx). The linked tools were user unfriendly, so their development continued and in the middle of the 1990s PDM had a strong foothold in the field of engineering. Of course, after this there has been development in the software itself, and the usability of PDM and CAD softwares are much improved from the early days. When companies recognized the benefits of a PDM system they started to add more supportive systems to the PDM, such as tools which control the manufacturing process itself. When companies also noticed that the spare part service was such an enormous business, PLM was added to the PDM to control the lifecycle and make the product related data easier to find at different stages of the company's production. The development of the PDM system can be found in the figure 1. [2]

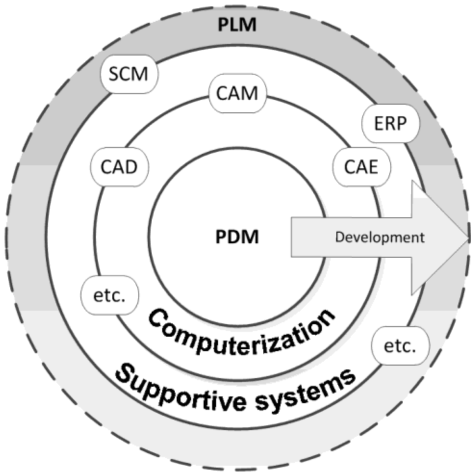


Figure 1. Development of PDM [modified 2].

The first PDM systems were file-based systems. All the documents were saved in a certain folder, so the designer had to know which drawing(s) belonged with each other. The usability of this kind of system was cumbersome and the arrangement relied very much on the users. If a user accidentally saved the file in a wrong folder finding it again was really time consuming. After some development the PDM systems started to be item-based systems (although in very small companies the file-based systems are still being used). In item-based systems everything relies on a certain part being identified. When the designer opens the information on the part, all the necessary datasheets should be available simultaneously. All these items should be easy to find with the help of the name and the item number. [3]

The main problem internally in companies is that knowledge is often in heads of the designers. However, everything should be saved to a system for further use. Könst et al. [3] has made a list of the typical things that are not in the PDM system. It may be really important to know in the future why a particular decision was made, where all the necessary files and papers are located, and what problem solving methods were used as solutions to the (experience-based) problems. These kinds of things may be hard to put into a file and save into the system. Nevertheless, PDM is still the right place for the documents and normally the final products have their own serial number under which it is easy to add documents for further use. [3]

1.1 Method, search procedure, and criteria

This search is based on a literature review and the author's own experience of PDM software. The main idea of this paper is to point out what can actually be entered into the PDM system. The scope is at a general level and the actual software base is excluded from this paper. It should also be recognized what the difference is between PLM and PDM, and why these two terms should not be confused. The emphasis of this paper is on PDM and PLM will only be briefly explained. When it is known what PDM actually is the term PLM will also become clear. In addition, knowing the main meaning of PDM will also clarify opinion on what kind of data can be added to this very useful system.

The literature search was done using a meta search via the data bases of LUT's (Lappeenranta University of Technology) library. The search was not limited to certain database(s), nor was a year criterion set up. The reason for this was that the author wanted to see what kind of development the PDM systems have gone through during the decades. The idea was also to find out what has been written and what the future trends and expectations for the PDM system have been. Furthermore, the author wanted to discover when PDM began to be called PLM.

2 THE BACKGROUND OF THE PDM SYSTEM

As mentioned earlier, PDM is not a software like CAD, it is a system which helps to handle and coordinate data which is created during the designing processes. Drawings, data sheets, and calculated test data are typical examples of data which can be added to a PDM system. The main point is that the data, which is in the PDM system, should be linked to the part(s) (later on: item) in such a way that it will actually help to manufacture the part(s) and make assemblies easier and faster. This may be the starting point of the actual PDM system development; as previously workers normally spent many years in the same company and during this time the knowledge of how things should be done developed. This led to a situation where many things relied on personal knowledge. This knowledge was really valuable to the company, and if the worker left then the information was also lost. Naturally this knowledge information should remain inside the company, therefore most of the information should be collected in the PDM system. How this can actually occur, needs more research.[3]

When a PDM system is needed, it should be linked with the company's strategy. Considerable amounts of information in a variety of different formats are created in the company every day. Globalization also brings new challenges in sharing the information and making it available to whomever may need it. Everyone involved has to have access to the information and in this case the PDM system can help: the system itself converts the files, for example, to pdf-format, so that everybody can open them no matter what the native file format was. One of the most important principles of the PDM system is that the information is easy and swift to find. As mentioned earlier, all the created data should be put in to the system, nothing should be based on a single engineer's knowledge. [3] As Stark [4] wrote: "Users need support from data management systems so that they will not discard potentially useful data".

Globalization is a challenge. Nowadays, the trend seems to be to have many offices in many different countries, and any created data has to be available 24 hours per day. The PDM system should "share" the information effectively, particularly in the beginning of the designing process. This is because most of the modifications to the product are necessarily made during the designing process. If the modifications are made to the product during production the costs will be higher. Figure 2 presents the relationship between the modifications and the cost during a certain phases. In the engineering phase there may be many designers from different companies (subcontractors) and the PDM system helps them to share the data and information. Of course the subcontractors have to have access to the PDM system, as this will guarantee that the co-operation works well. This leads to the conclusion that the PDM system is no longer an option for large companies – it is a necessity. [3]

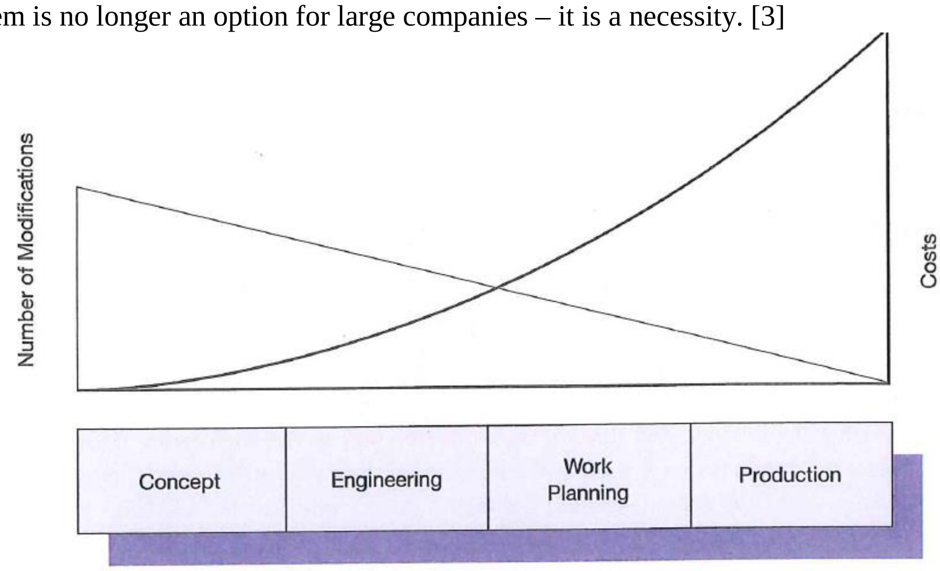


Figure 2. Phases where most of the modifications occur and the relationship between the modifications and the costs [3].

Different companies produce different kind of products, so it is important to have a custom-made PDM system catering to a company's own needs. The structure of the system depends on what kind of products are being manufactured and on the batch size. PDM systems always have basic modules, such as a warehouse for information and structure management. Selecting the right system is time consuming and the company first has to recognize their own needs and what is really required from the system. It also has to be considered what kind of designing software is already in use, and who the main group using the PDM system will be, as well as their requirements from the system. [4]

2.1 PDM became PLM – what were the reasons

When discussing lifecycle systems is has to be determined which kind of lifecycle is being used in each case. Similar to the product, the data also has its own lifecycle. Datasheets that are in the PDM system may expire after certain time. It also may be the case that some components are not available after one or two years and after this time period maintenance of an old product is difficult. Of course in such a case any new components have to be added to PDM system and the related drawings updated. This can then be called a PLM system; without any updates the information in the PDM system becomes so old that the information cannot be used without major problems (for example, in production when the same kind of products are created again). [4, 5] PDM itself cannot handle the lifecycle information. The main reason for this is that the PDM system is only developed to support the designing processes. On a general level, the purpose of PDM is simply to make sure that everybody has access to product data. [7]

The main reason why the terms PLM and PDM are often confused is due to the handling of the product data. Figure 3 indicates where the PDM system commences the action and where the PLM system is introduced. After designers have created the information it may also be needed later, for example, when designing new structures that are based on the old design. However, one important detail is missing from the figure 3. When, for example, replacing an old part whose lifecycle has come to an end, then the role of the PDM system is again required. After this replacement, the PLM system starts functioning again and so these two systems always work together. [6]

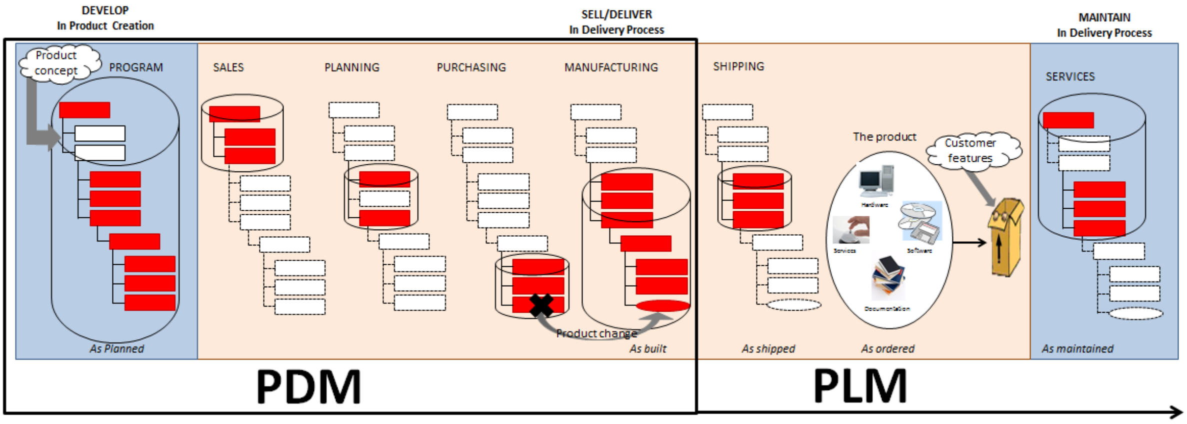


Figure 3. PDM and PLM working areas [modified 6].

In some cases, PLM is just a term that focuses on the last stages of the product. These stages are, for example, the disposal and environmental aspects. Normally, these stages do not concern the producing company at all, so in this paper it can be said that the PLM system just takes care of the product as regards the aspect of maintenance and spare parts. Moreover, the PLM system starts its action when the designer has approved his design. [7] Therefore, the core processes of PDM are [7]:

- Planning / offering processes
- Product design / process planning
- Manufacturing / assembly

Subsequently, the core processes for PLM are (in this case) shipping and maintenance.

However, the main problem still remains: PDM only handles data - not knowledge. This is a problem because knowledge is usually the base for designing. Companies often produce similar products, therefore to save time the designers frequently take an old design as the basis for a new one. In these cases it is crucial that the information in the old designs is correct and all the necessary data sheets/ files are available. Figure 4, shows the characteristics and properties of the product and their relationships. The characteristic features are features that the designer can actually choose according to the properties. [8] The characteristics tree on the left side is similar to the structure of the product in the PDM system. When designing a product it would be of considerable benefit if the PDM system could actually help the designer simply by recognizing the part and making a suggestion as to what kind of data sheet should be added to the item in the PDM system. In addition, the system could suggest what kind of designing aspects should be taken in account during the designing process. In this way the number of modifications during production could be reduced (cf. figure 1).

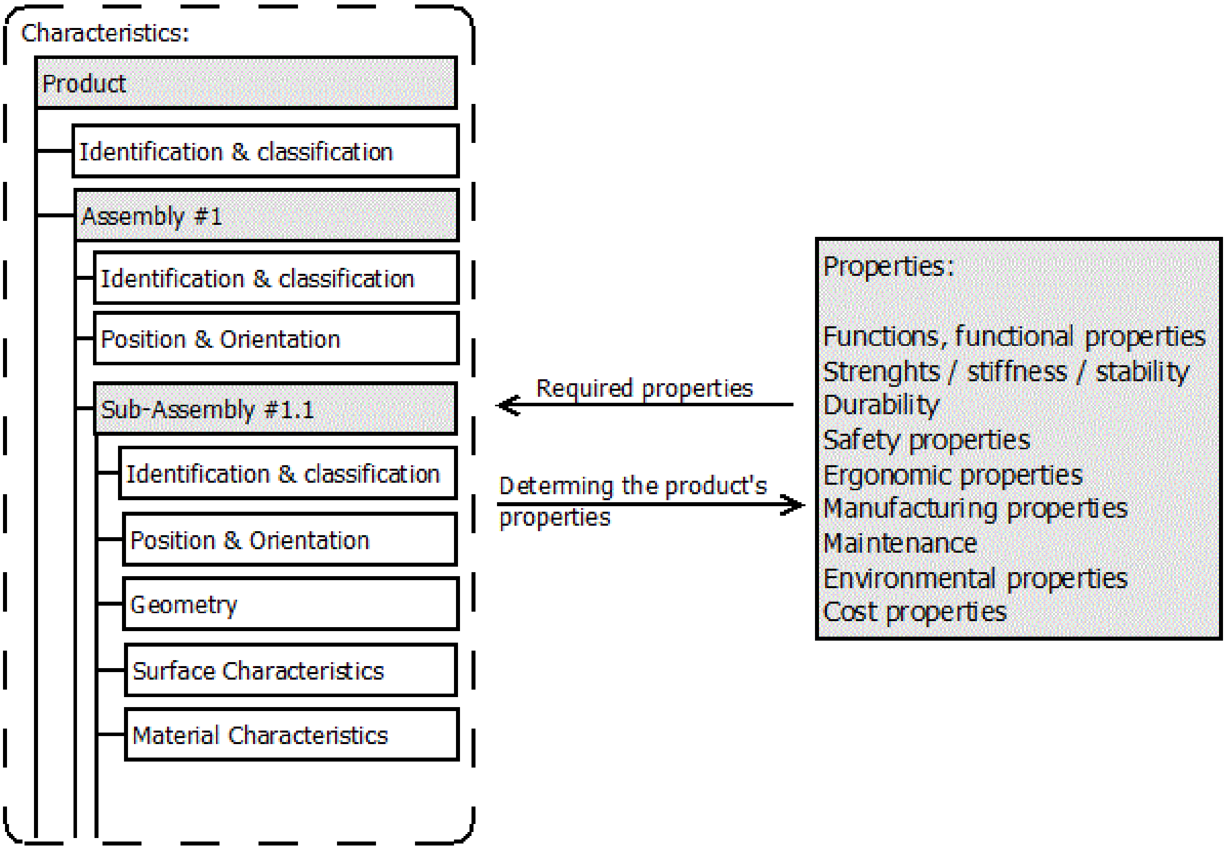


Figure 4. Characteristics and properties of a product [modified 8].

3 CONCLUSION

Könst et al [3] simplifies the term PDM by defining the individual letter. When discussing the PDM system the letter P stands for the product. The product should be the centerpiece and all the information collected around it. All product-related information should be available and added to the PDM system and this information should also be relevant. The main goal is that a search for any required information can be made in the PDM system under a certain item, and not anywhere else. The letter D is for data and denotes all the information related to the product, which has to be up to date, otherwise the designing process, and of course the manufacturing process, may be impossible to complete. Additionally, the data is all the information that is created during the product development process. The final letter is M (management), the main meaning of which is control. Control means controlling both the data and the product, i.e. making sure that the data is available to all parties and the products data sheet(s) are up to date. [3] After internalizing these three main aspects the product data in the PDM system should be correct.

Simple stated, it can be said that the whole purpose of the PDM system is to manage the activities of the product during its lifecycle. Managing activities means that the system has to be flexible so that it is easy to use, that the information is easy to find, and that making changes is easy. However, the reason why the PDM system should be purchased and included in the company's strategy is that with the help of PDM: the productivity can be improved, people can have better access to information, and it is easier to manage data, which is related to different kinds of products. [4] Figure 5 shows the differences between the information in a PDM system and a PLM system. As can be seen, the same kind of information can be in both systems. The reason for this is simple: PDM supports PLM and also in some cases PLM is supports PDM.

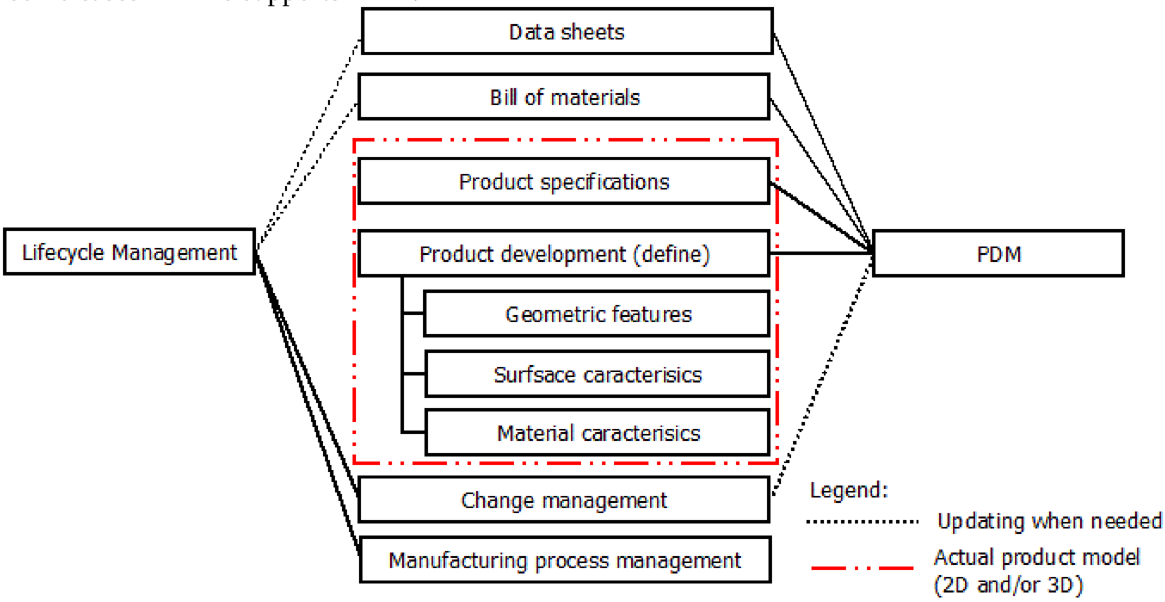


Figure 5. Functions which are included in lifecycle management and PDM.

PDM should support more efficiently the actual designing process. The support should include features such as the PDM system recognizing a part when it is saved to the system for the first time and when the designer selects the name and the group for it. With the help of this feature, it can be assured that all the correct designing aspects have been taken into account and all the necessary data sheet(s) are added to the part. This will lead to the parts being more easily manufactured, as well as considerable time saving. In the future, other similar parts will be easier to manufacture and design when the designer knows that the old part is correctly designed and documented. However, this will also need more co-operations between the manufacturing and the designing departments. If the manufacturer notices something erroneous they will have to inform the designer so that the drawings can be corrected.

References

[1] Huhtala, M. & Lohtander M. & Varis, J. Confusing of terms PDM and PLM: examining issues from the PDM point of view. The 22nd International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2012). Ferry Cruise Conference Helsinki-Stockholm-Helsinki 10-13 June 2012.

[2] Moorthy, ABG. and Vivekanand, S. Integration of PLM with other concepts for empowering business environments. Product Lifecycle Management. Assessing the industrial relevance, PLM'07. Italy. 2007. Pp. 93-106

[3] Könst, J.S. & la Fontaine, J. P. & Hoogeboom, M. G. R. Product Data Management – A Strategic Perspective. Maj Engineering Publishing. 2009. 103 p.

[4] *Stark, J. Product Lifecycle Management: 21st Century Paradigm for Product Realisation. Springer. 2005.441 p.*

[5] *Kemppainen, T. & Kropsu-Vehkaperä, H. & Haapasalo, H. Introducing Product Data Ownership Network. Research Reports in Department of Industrial Engineering and Management 1/2011. University of Oulu Research Reports in DIEM. 2011.*

[6] *Kropsu-Vehkapera, H. Product structure and lifecycle management: A systematic literature review. The 3rd Nordic Innovation Research Conference - NIR 2008—IEM Arctic Workshop. 2009.*

[7] *Abramovici, M. & Gerhard, D. & Langenberg, L. Application of PDM technology for Product Life Cycle Management. Proceedings of the 4th International Seminar on Life Cycle Networks. Berlin. 1997.*

[8] *Weber, C. & Werner, H. & Duebel, T. A different view on Product Data Management/Product Life-Cycle Management and its future potentials. Journal on Engineering Design. Vol 14, No. 4, pp. 447-464.*

ISBN 978-952-265-386-4
ISBN 978-952-265-387-1 (PDF)
ISBN 978-952-265-388-8 (memory stick)
ISSN-L 2243-3376
ISSN 2243-3376

Lappeenranta 2013