

# Integrating Product Structures, Production Processes and Networks for the Development of Product Families

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## Abstract

In this paper we present the mind-set of Conceptual Design for Manufacture and Assembly that integrates the viewpoints of product design, production processes and supply networks. The mind-set is applied in a model of generic product structures as well as the structures of production processes and supply network. The mind-set is based on literature as well as the practical needs of industrialists in three globally operating companies.

Our emphasis is on the analysis of product variants in production processes and logistics. We present a case study in order to validate the model and illustrate the mind-set. We argue that integrating the different viewpoints is necessary for the pervasive evaluation of new product concepts within the variety space of existing and targeted product families.

**Keywords:** Integrated product development, Product families, Production processes and networks

## 1 Introduction

First, let us take a brief look onto old tenets of product development. Second, we will briefly present our outlook on the situation in practise nowadays. This will provide us with a motivation as well as a problem set-up for the research presented here. As a summary, the recent changes indicate evolution towards multi-product development in a context of a globalized value chain. This poses new kinds of challenges to product development practises.

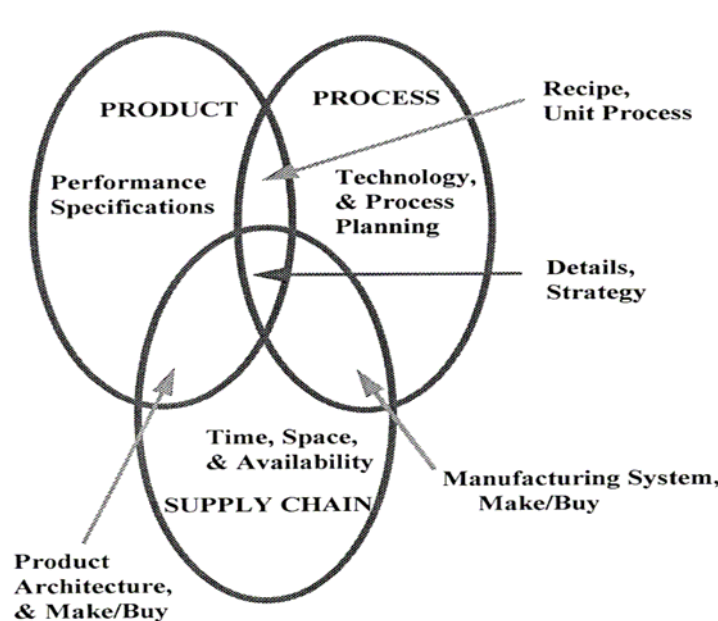
### Integration in product development

Integrated product development (IPD) by Andreasen and Hein [1] accentuates the management and co-ordination of product development project(s) by integrating strategic, continuous product planning processes to product development projects, which integrate business functions within a company. The activities of product synthesis and general problem solving process take place in a number of stages in both the (strategic) product planning processes and in the practical product development projects.

Concurrent Engineering (CE) is another concept from the 1980's that has been accentuating systematic approach together with life-cycle thinking and taking into account product properties as a whole, e.g. quality, costs and timeliness. Cleetus has also summarized that in CE:

“Response to customer expectations, and life-cycle perspectives early in the process... are incorporated by adhering to *team values of cooperation and integration* that provides ... *large intervals of parallel working that is synchronized by comparatively brief exchanges*”. [2, p.3]

This has led to the suggestions of generic models on the firm and on the engineering cooperation and coordination [2]. Moreover, an evolving set of methods and tools, such as Design for X methodologies (DFX) and Design Structure Matrix (DSM see: [www.dsmweb.org](http://www.dsmweb.org)), have been introduced. They can be considered as a part of CE.



**Figure 1. Overlapping responsibilities across Product, Process, and Supply Chain development activities according to Fine and Cohen [3, p. 219]**

From the late 1990's Cohen and Fine have been advocating the concept 3D Concurrent Engineering (3-DCE). In respect of the models of IPD and CE, the major difference is in the integration of supply chain into product development. 3-DCE model relates product concept to not only to production concept but also to the supply chain concept (see figure 1).

Further, product design specifications and architecture are related to unit processes and supply chain architecture via technological and architectural decisions. Also, the decisions of production focus are based upon the relation of manufacturing and logistics as well as coordination systems. Thus, 3-DCE can be regarded as an addition to the existing tenets of product development with a supplement of architectural and production focus related issues.

#### **Challenges and suggested solutions**

The practise of product development is being challenged by the increased need of productivity. Typically, design productivity is being measured by the *effectiveness*, e.g. the quality of product (assortment), and the *efficiency*, e.g. increasing rate of different products released into markets, of product development [4]. Also, the increasing complexity of products is a challenge to the design productivity. Generally, the dilemma of productivity has been approached by disintegrating product structures to modules and separating the product development project to product (family) architecture development and to module development projects. Moreover, design pre- and re-use is accepted as a strategy to tackle the

problem of productivity as well as the outsourcing of the design tasks an operative action for increasing the efficiency of product design.

The development of product families is a solution to some of these challenges. Unlike IPD or CE, the recent suggestions for product development, e.g. by Andreasen et al. [5] and Simpson et al. [6] are aimed at multi-product development. These are either very abstract or require detailed (operative) data and the practical application of present models in developing new product concepts is scarce. Also, a recent study [7] implies that the IPD-model is basically valid even in the case of multi-product development and only requires revisions, such as the one made with 3-DCE.

#### **DFX-methods**

Whitney [8] has categorized DFX-methodologies into two classes

1. Methodologies relating one part or part type to its relative characteristics e.g. ease of assembly, as well as procedures that can be applied by a single individual engineer.
2. Methodologies aimed at considering a product as whole, such as all parts of an assembly, and procedures, which are meant for the design team (supporting integrated product development)

Both of these approaches appear problematic in practise. For example, the strategic integration of different disciplines, such as production, product design and marketing, is usually not as straightforward as the IPD-model suggests. Furthermore, the global supply chain may effectively inhibit the integration of different disciplines. Also, our industrial partners have reported that the companies' production units or outsourced suppliers can seldom evaluate the manufacturability of parts or the ease of assembly without detailed descriptions of products, assemblies and parts. Instead, the production engineers typically phrase "*first design it and then we can tell what is wrong*". Typically there are neither abilities nor time to make such kind of analyses as commonality analysis in an industrial product development projects.

Logically, the detailed designs do not exist at the conceptual stage as the design activity is unfinished. Also, the detailed approach of some methods, such as the one by Boothroyd et al. [9], require the detailed information about the product assemblies, components and parts as their approach is from bottom to top. Often, the existing DFX-methods focus into product characteristics and their relation to a part of the task or process, such as accessibility and visibility in part orientation and insertion in assembly.

Therefore, the analysis is focused onto sections of the production processes. Even though the sections may have been decisive for the process as a whole in the past, this assumption may be invalid in the present situation, where product variety and globalization of the supply chain dominate. As can be seen from the figure 2, the traditional cost saving methods like Design for Die-casting, Design for Machining and Design for Assembly consider only the value added time. Moreover, Fabricius [10] has emphasized the importance of top-down approach already with the traditional DFX-approach. Hence, a more generic approach, which takes into account logistics as well as supply networks is needed.

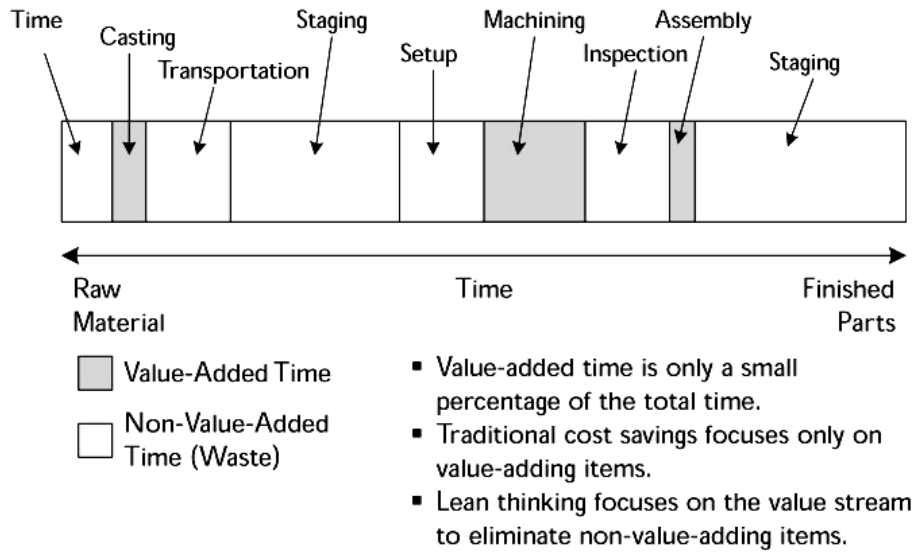


Figure 2. Waste in a value system [11, p.30]

### Scope and objective

We base our research on the IPD-model as we relate the target of our contribution to the early stages of the model: product planning, need recognition and the generation and evaluation of a number of principal solutions. As a combination the need recognition and principal solutions create the conceptual stage of product development.

The basic assertion in this research is that the bottom-up analysis based on the relation of detailed designs and atomic operations leads companies astray. Instead, a higher level analysis of produceability is required in order to judge the viability of product (family) concepts. We base this idea to the observations reported above.

Our aim is to support the integration of product development by providing means for the modelling and the assessment of product (family) concepts in relation to (production) process concepts as well as production network structures.

### Research method

We propose a matrix methodology for analyzing the 3-DCE combination over the variety space of a product family. We validate and verify the methodology in a real product development case. The case is about re-engineering an existing design that is being applied in a number of product families.

## 2 Theoretical background

Suitoranta [12] has presented a theory that relates the concept of product variety space with an extended concept of cost. He argues that each of the seven virtues (see [10]) can be condensed as a measure of extended cost. A life-cycle phase is related to the concept as it bears the role of a cost carrier. According to this frame of thought quite a similar concept to extended cost is the concept of waste in lean production (see table 1.).

When considering a variant in a production system, many of the categories of waste appear. If a variant is not needed, it is a case of over-production and/or overprocessing. Also, the

production of variants can easily lead to excess inventory and the need of estimating as well as waiting. Thus, there seems to be a strong reason to consider variants within 3-DCE framework.

**Table 1. Eight categories of waste [11, p. 28-29]**

Over-production	Waiting (time on hand)
Unnecessary transport or conveyance	Overprocessing or incorrect processing
Excess inventory	Unnecessary movement
Defects	Unused employee creativity

The counterpart of variety is commonality, which is the relative property of a product or its part in respect to the life-phase system it meets. By calculating a commonality index within each production sequence it is possible to create a commonality function of production sequence [8]. The virtue of late-point differentiation suggests that the commonality function should be monotonically decreasing. However, instead of calculating commonalities, we may just sum all the variants existing in the step of a production sequence. We argue the product family variety function of the sequence should (ideally) be monotonically increasing, as a deviation from this argument poses a threat of waste.

In the theory of Ideal Factory [13], the basic production processes are considered to be blank supply, parts manufacturing, module assembly and final assembly. These form the finite number of elementary activities that are used in creating the steps of production sequence for a product concept. For example, a product concept can be comprised of injection moulded parts. Therefore, the combination of variety of polymer materials and colours do exist in supply, i.e. the first step of a sequence, and counting them as a variety for step *materials supply* makes sense. Adding the time related to logistics between sequence steps and processing time in each step makes it possible to make an ordered sequence in a timeline. Also, it is possible to analyse the variants of the steps of a production sequence and to create a product family variety function of production process (as a whole). The time related to logistics is dependent to the configuration of a supply chain. Thus, it is possible to create a product family variety as a function of (extended) production time. The function should show moderate level of variety in the early steps of a production process, but accelerate to demanded level of variety at the final steps of process. Also, the slope of the curve, i.e. the derivative of the function, should monotonically increase and the shorter overall lead time is, of course, the better than the long lead time, as the work in progress (WIP) tends to be small with the short lead time.

### **3 Methodology**

Malmqvist [14] has presented categorizations on matrix tools and methods. Matrix tools used for modelling products in various purposes are classified into three categories: element-level matrices, product-level matrices and matrix methodologies.

Element-level matrices represent relations between components or modules of a single product. Malmqvist [14] has divided this category furthermore into two subclasses: intra-domain matrices and inter-domain matrices. Intra-domain matrices deal with relations between same types of elements while inter-domain matrices represent relations between

different types of elements. Product level matrices are to represent whole products rather than parts or elements of products. The class of matrix methodologies discusses methodologies that use multiple matrices in a coherent fashion. There can be seen a synthesis among these matrices.

In the utilization of the theory we applied both intra- and inter-domain matrices in three domains, according to the 3-DCE [3]:

- The elements of **product** (family) concept.
- The elements of production **process**.
- The elements of production **network**, i.e. the supply chain.

For the sake of simplicity we will call these domains plainly as product, process and network domains. Within each of the domains a dedicated intra-domain DSM-matrix represented relations in a domain. In product domain the rows and columns represented the items of product at different levels of detail, such as materials, blanks, parts, sub-assemblies and final assemblies. Moreover, some columns were dedicated to indicate the number of variants over the items of product. The cells in product-DSM represented the constitutive relations between the items. For example, an assembly “box” is composed of six parts “walls”, which in turn are composed of a metal sheet blanks. Each of these is having a number of variants (see Figure 3).

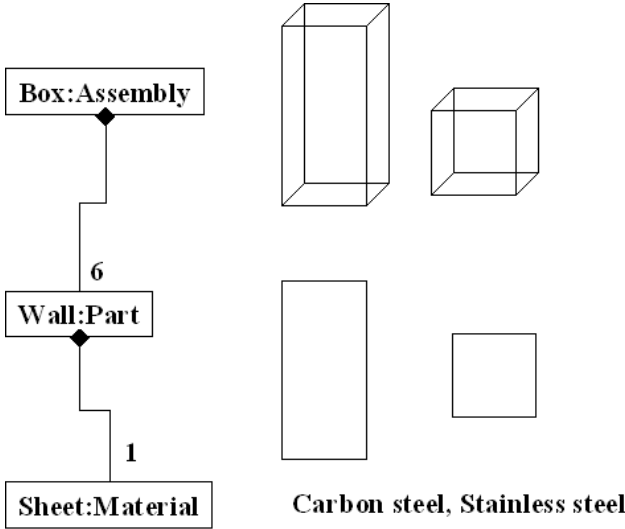


Figure 3. A simple example

In an extended DSM the simple example is modelled as presented in table 2. There the dimensional and material variants of a box, walls and sheet are marked with numbers in the rightmost three columns. As a one sheet is used for each part, the number 1 is added to the cell indicating the relation of sheet and wall in the DSM-part of the matrix as well as the constitutive relation between wall and box.

Similarly to above, in process domain matrix the rows and columns represented the production activities, such as blank casting, part manufacturing, welding, assembling, etc. The DSM indicates the order of processing activities.

**Table 2. Extended DSM for the simple example**

	Material: Sheet	Part: Wall	Assembly: Box	Number of Variants as a product of...	dimension variants,	material variants, etc.
Material: Sheet		1		2	1 (thickness)	2
Part: Wall			6	4	2 (sizes)	2
Assembly: box				4	2 (sizes)	2

The attributes of interest, such as processing time or cost, can be added to the process DSM, as in the case of the number of variants in product DSM above. Also, the elements of network, such as production sites are represented with rows and columns in network DSM. The cells of network DSM can represent the relations, such as transportation time and storage, between different sites. Actually, these represent the non value-added time (see figure 2).



**Figure 4. The states of elements in part manufacturing**

The intra-domain matrices are used here to represent the relation between products and processes as well as processes and network. Logically, the activities create transformations between the states of a product (see figure 4). In a matrix representation this means that a row or a column in process DSM (transformation in Fig. 4) should point out in between two rows or columns in product DSM (state in Fig 4). However, this can be avoided by relating states with activities with signs indicating if a state is an input or output to an activity. Eppinger et al. present an example of this with a task-based DSM for component design in [15, p.6].

As a summary, we have six possible matrices that represent the characteristics as well as the intra- and inter-domain relations of elements in three domains. There are multiple variations how the matrices can be used. For example, the matrices can be used in representing the relative characteristics and properties of a product family. Moreover, the methodology can be used as a tool for evaluation competing concepts of product, production and supply network.

### 3 Case study

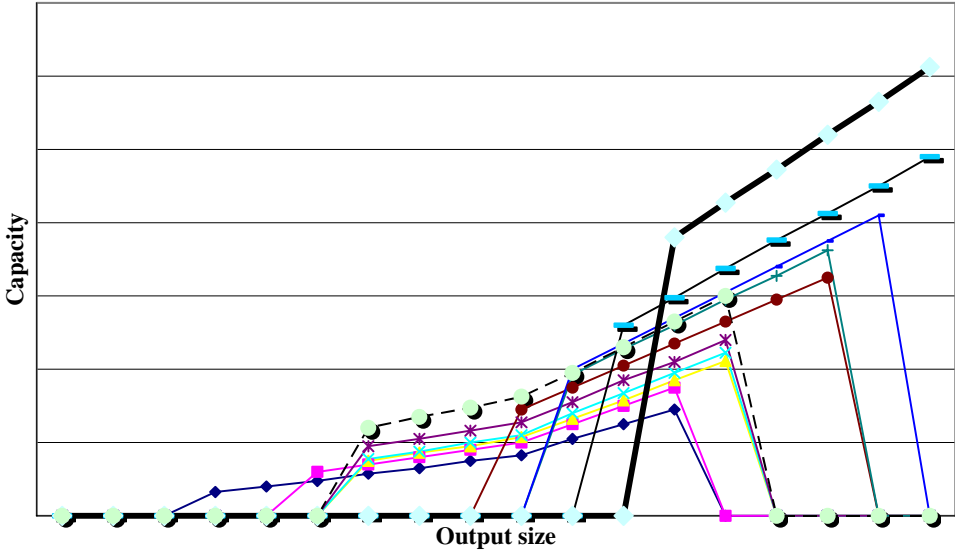
We tested the methodology in a real world case, where a competing concept for an existing jaw crusher family was about to be developed. The design itself is very old one and its properties and characteristics vary a lot according to intended functional, performance and application specifications. In re-engineering the variety is planned to remain as it is. This meant maintaining the number of configuration options and alternatives. The variants existed due to different choices of functional properties, the level of automation and the choices of safety systems as well as due to relations to external systems, such as mechanical and electrical interfaces. Thus, the main objective of the development project was to improve the relation of a design and its life-cycle (primarily in production) rather than to introduce new kind of functionality or to improve the performance the product (in use phase).

Before the application of the methodology, it was clear that the intra- and inter-domain matrices could relate the elements of 3-DCE. Especially, delays due to logistics as well as the variation within the family were of our interest. However, the methodology was being developed during the case and, therefore, the case is an example of action research with three iterative steps: a) data collection, b) modelling and c) review and analysis. The steps were iterated about a half a dozen times, beginning with initial models and ending into refined models for different purposes.

In a set of meetings with the representatives of the company, the data was being collected and models reviewed. Participants of the meetings included product and production specialists, who clarified the variants of the product, the issues of production procedures and network structures. Both the existing product family concept as well as the competing concept were being clarified and modelled. The 3D CAD-models of the existing concept were available right from the start but no detailed 3D-models of the competing concept.

**Top-down approach: documenting and visualizing product variety and production process**

We studied the existing range of external variety in the product family by analysing the main properties of crushing process and the (optional) functions of the crushers. The data for making this was available in company’s marketing and sales material. As Figure 5 shows the existing range was quite much overlapping from the external variation point of view. Further questions and suggestions to re-engineer the product family as a whole were suggested. After this we could proceed to more in depth analysis of the design of competing concepts and structure of the production process.



**Figure 5. The variety of main properties of existing product family**

We studied the production process by studying the lead time with different concepts and production networks. Our focus was on the lead time, which was decomposed according to subsystems, such as modules and parts – the lead time of the blanks and the materials of parts was also studied. In this task we illustrated the options with a work breakdown structure, where each substructure represented the lead time of a subsystem.



## Results: visualizing relative properties

Data in the matrices was being visualised with a number of graphs. For, example the Figure 6 presents the variants of competing product concept as a function of time. The different options of concepts were illustrated, compared and presented for decision making.

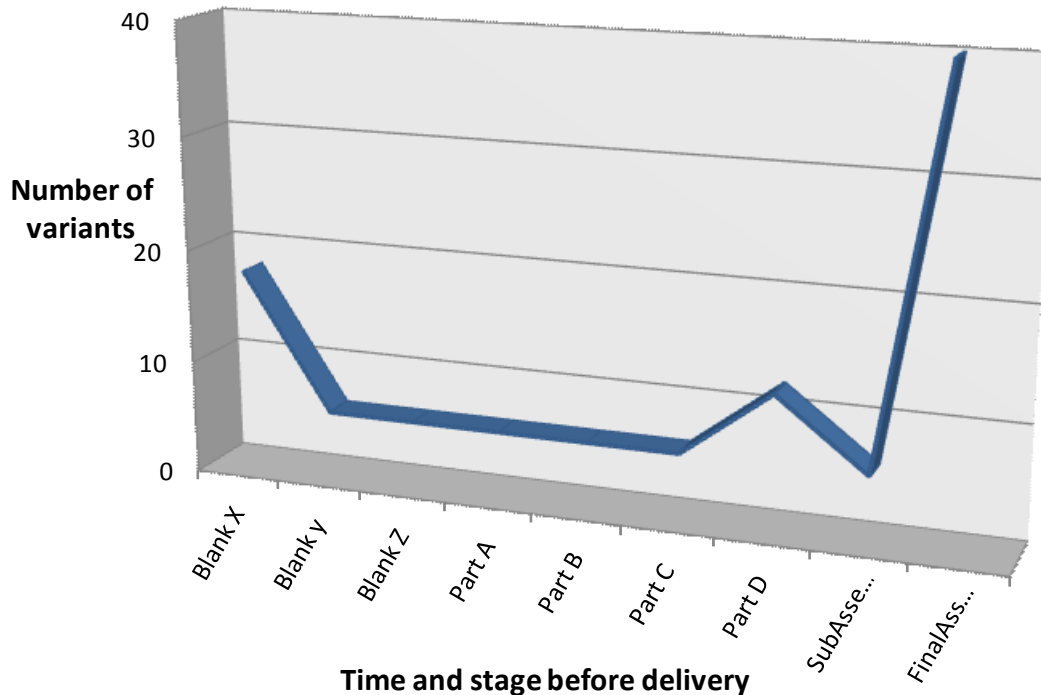


Figure 6. The decomposition of variants as a function of production time (including logistics)

The experiences attained from the case were positive, because the new combination of product, production process and network concepts could be brought together and relative properties presented. However, the matrices became quickly quite large and therefore difficult to manage. Thus, the more sophisticated methods, possibly integrated with PLM solutions, are currently being considered.

## 4 Conclusions

In this paper we emphasize the importance of taking a broader view of product produceability than with the traditional set of DFX-methods. We also stress the importance to being able to analyse the produceability and variety of product family concepts early in the development project. We also suggest a matrix methodology for enabling the integration of different viewpoints.

However, the research to integrate the viewpoints is unfinished and currently the methodology itself is at the conceptual level. Therefore, the results so far are tentative, but promising.

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## References

- [1] Andreasen, M.M., Hein, L. Integrated product development. Institute of Product Development, Technical University of Denmark, Copenhagen. 2000. 205 pp. (original publication by IFS publications in 1987)
- [2] Cleetus, K.J. Concurrent Engineering Vision. Technical Report CERC-TR-RN-92-018, Concurrent Engineering Research Center West Virginia University, 1992. Available in: [www.cerc.wvu.edu/cercdocs/techReports/1992/cerc-tr-rn-92-018.pdf](http://www.cerc.wvu.edu/cercdocs/techReports/1992/cerc-tr-rn-92-018.pdf) (accessed at 1.5.2008)
- [3] Fine, C.H. Clockspeed-Based Strategies for Supply Chain Design. In: *Production and Operations Management, Vol No. 3, Fall 2000*. pp. 213-221. Copyright © 2000, Production and Operations Management Society.
- [4] O'Donnell, F. J., Duffy, A.H.B. *Design Performance*. Springer-Verlag. 2005, 215 pp. ISBN: 978-1-85233-889-3
- [5] Andreasen, M.M., McAloone, T. Mortensen, N.H. *A P\* insight report on multi-product development – platforms and modularisation*. Technical University of Denmark, Lyngby, Copenhagen. 2001. 91 pp. ISBN: 87-90130-34-0
- [6] Simpson, T.W, Siddique, Z., Jiao, R.J. Platform-based Product Family Development. In: *Product Platform and Product Family Design: Methods and Applications*. Edt. by Simson et al. Springer; Corrected 2nd printing edition, 2007. 548 pp. ISBN: 0387257217
- [7] Pulkkinen, A. *Product Configuration in Projecting Company: the Meeting of Configurable Product Families and Sales-Delivery Process*. Doc. Tech. dissertation, Tampere University of Technology. Publication 712. 2007. 184 pp. ISBN: 978-952-15-1897-3
- [8] Whitney, Daniel E. *Mechanical Assemblies – Their Design, Manufacture, and Role in Product Development*. Oxford Series on Advanced Manufacturing. Oxford University Press. 2004. 544 pp.
- [9] Boothroyd, G., Dewhurst, P., Knight, W. *Product design for manufacture and assembly*. Marcel Dekker, New York, 1994. 540 pp.
- [10] Fabricius, F. *DFM – guidelines for improving the manufacturability of industrial products*. Eureka Secretariat, Brussels, 1994.
- [11] Liker, J.K. *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill Professional Publishing, 2003. 330 pp. ISBN 007-1392319.
- [12] Suistoranta, S. *Origination and propagation of costs in the variety space of industrial products : contribution to the concept of cost in design science*. Doc. Tech. Dissertation. Tampere University of Technology. 2007. 117 pp. ISBN: 978-952-15-1745-7
- [13] Lapinleimu, I. *Ideal factory : theory of factory planning, produceability and ideality*. Doc. Tech. dissertation, Tampere University of Technology. Publication 328. 2001. 195 pp. ISBN 952-15-0614-8
- [14] Malmqvist, J. A Classification of Matrix-Based Methods for Product Modeling. In: *The Proceedings of International Design Conference - DESIGN 2002*. Dubrovnik, May 14 -17, 2002. pp.203-210
- [15] Eppinger, S.D., Whitney, D.E., Smith, R., Gebala, D. A Model-based Method for Organizing Tasks in Product Development. In: *Research in Engineering Design*, Vol. 6, No. 1, pp. 1-13, 1994.