NordDesign 2014
August 27 – 29, 2014
Espoo, Finland / Melbourne, Australia

Integration Framework for Product Development and Production Development

Pascal Stoffels[1], Frank Litwa[2], Christian Gerlach[3], Michael Vielhaber[3]

[1]ZeMA gGmbH, pascal.stoffels@mechatronikzentrum.de
[2]Daimler AG, frank.litwa@daimler.com
[3]Institute of Engineering Design, Saarland University, Germany,
christian.gerlach@uni-saarland.de, vielhaber@lkt.uni-saarland.de

Abstract

Due to shorter lifecycles and an increasing product complexity, the development of products and the respective production systems is more and more performed simultaneously. Nevertheless, both domains are often synchronized through common milestones, only. The application of different methods, processes and IT-tools is common practice. This situation potentially leads to suboptimal results concerning integrated aspects such as environmental impacts or even to quality problems on integrative tasks such as tolerance management or change management. For this reason the question arises, if and how both process streams could be interlinked any deeper in order to minimize such problems. This paper presents an integration framework along the three example integration fields of tolerance management, change management and eco engineering.

Keywords: Simultaneous engineering, tolerance and change management, eco engineering

1 Introduction

The lifecycle of a product and the lifecycle of the respective production equipment intersect in the production phase of the product, which at the same time represents the use phase of the production equipment. In this phase, both spheres have to fit together. In modern series production, products and production equipment are therefore often developed simultaneously. From a process perspective however, the integration of both domains is rather low. Product development and production (equipment) development follow more or less independent pathways from a conceptual design via a component design to a system integration phase, only synchronized through project milestones, see figure 1, and potentially supported by "design for the other domain" guidelines. In most companies, both domains' processes are owned by independent organizational units, they use different terminology, methods and tools. [1, 2]

The low level of integration may lead to suboptimal results, e. g. regarding the minimization of environmental impacts across the complete product creation process, or even to quality problems on integrative tasks such as tolerance management or change management.

This leads to the questions, if and how both process streams could or should be interlinked any deeper or mutually adapted any further, and if an integrated methodology would be reachable and desirable. These questions set the frame for the presented research work.

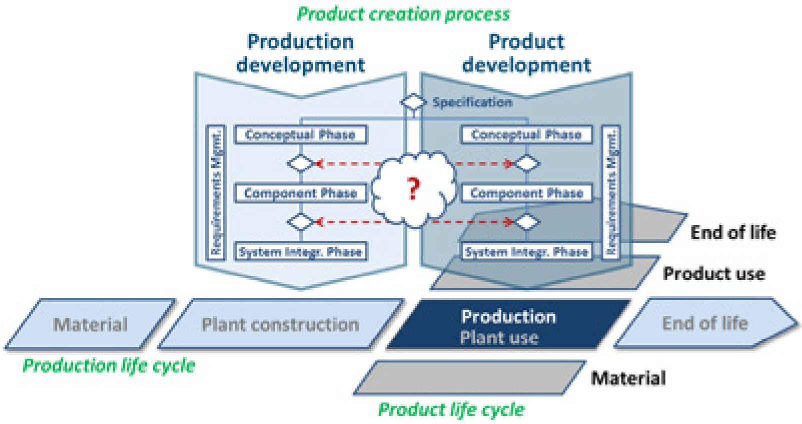

Figure 1 Product/production development & lifecycles (similar to [2])

1.1 Approach

To answer these questions this paper investigates three example integration fields: tolerance management, change management and eco engineering (sections 2-4).
These three examples are currently in focus of the authors within a complex automotive body-in-white environment. In each area, extensive interview studies have been conducted by the authors at an automotive OEM. The examples show that they are well suited to comprehensively cover the integration of the product development and the production development domain. Tolerance management stands for technology-based integration aspects influenced by domain specific as well as domain spanning factors. Change management is similarly interlinked across both domains; it stands for organisational integration aspects, accordingly. Both tolerance and change management feature well established processes, methods and tools across both the domains in focus. Integration approaches in these areas will therefore have to take legacy solutions well into account. In contrast, eco engineering of both products and production facilities is an in comparison new integration area with not deeply integrated processes, methods and tools, yet. It may therefor offer opportunities to implement integrated simultaneous engineering approaches right from the beginning.
For each integration field, deficits are identified and local process, method and tools approaches are presented. Then, section 5 derives conceptual answers and conclusion regarding an integration framework for product and production development.

1.2 Product and production development

Although simultaneous engineering is well established on a high conceptual level, on the operational level (in industrial practice) product development and production development still follow different processes, and both domains apply different methods and tools. In [2], the authors present results from a literature study giving an in-depth comparison of the domains by looking at the three dimensions of processes, methods and tools, which have shown to be appropriate for engineering process analyses and syntheses [3].
Main findings from the comparison concerned terminology, process, method and IT incompatibilities and lead to the proposal of an integrated product and production development framework. In the following, this framework will be further developed and detailed along the three example integration fields.

2 Tolerance management across product and production development

To fulfil the customers' growing demands in quality, it is more and more necessary to give a statement about product properties at any time of the product creation process. With regards to requirements like aesthetics, functionality and degree of reproducibility or manufacturability, the technological solution for enterprises is rigorous tolerance management. Tolerance management breaches the gap between product and production-development and is able to fulfil the requirements shown above [4]. Therefore, it is necessary to provide and combine information from both domains' development processes. This means that for all three main development stages (conceptual design, component design, system integration), simulation models consist of information from both product development and production development databases as well as respective expert knowledge.

2.1 Situation today

Today, if at a specific development stage e.g. the dimensional accuracy of the product with regards to the series production processes is investigated, the usage of tolerance simulation is a helpful tool. The build-up of such simulation models is time consuming. Also, these simulations are susceptible to changes in the development process, see section 3. If changes in the product or the process occur during development, the tolerance simulation model has to be reworked to grant significant results. To give an application example tolerance management in automotive industry is used. For each development stage it should be shown which domain specific data is used to build-up a tolerance simulation model.

During **conceptual design**, to secure the conceptual model for requirements like aesthetic and manufacturability different kinds of tolerance simulation models are created by the tolerance management department using a variety of information. Due to a limited maturity level of product and production data in this early development stage the simulation models are created from conceptual information (e.g. class A-surfacing data) and experts knowledge (e.g. previous models). In this phase, tolerance simulation models are created to secure the functional requirements of gaps in an early stage, to visualize the effect of gaps, and to define the alignment of external parts of a car (fender, hood, windscreen, etc.). The proceeding **component design** process allows building up more detailed tolerance simulation models. For this reason, the simulation models are built from both product and production development data. Furthermore, the insertion of experts' knowledge is indispensable. For example at this development stage the tolerance simulation is performed to secure a specific scope of data (e.g. cockpit, tail lamp). These simulations are also aiming at manufacturability and aesthetical requirements of the product. In the **system integration** phase, to secure a module-spanning scope of the data (e.g. dimensioning of tolerance compensation elements) the complete development information is required to build up a tolerance simulation model. Hence to do so, an experienced modeller is required to understand module-spanning interactions of parts and components. Here again the experts knowledge is indispensable for correct simulation.

2.2 Deficits

In summary all tolerance simulation tasks during the development process are suffering from similar deficits which can be divided into process deficits, IT deficits and methodical deficits.

2.2.1 Process deficits

During the development process parts and components frequently change in shape. The ambition for simultaneous engineering in large scale enterprises, e.g. the automotive industry, causes problems in an adequate pretesting by simulation. The concurrent changing in product and production data leads to simulation models that may be outdated due to their time consuming build-up process, but that should serve as a basis for decision making.

2.2.2 Tool/IT deficits
Each development domain or process is generally based on a self-contained development environment using its own data management methods. In large scale enterprises, these development environments have grown over several generations. They have developed independently due to increasing, mostly domain-specific demands. They may work inefficiently because of task-based partial solutions. Furthermore, multiple formats are used what makes an automated information exchange difficult [5]. Regarding tolerance management, there is no adequate solution today for storing the experts' knowledge on tolerance simulation models.

2.2.3 Methodical deficits
The storage of development data in different data formats only allows a manual build-up process of tolerance simulation models. Moreover, an experienced modeler is required to handle complex part interactions (e.g. for mapping over-constrained situations into a static model) and to update the tolerance simulation model, accordingly.

2.3 Approach
As mentioned in the previous chapter, tolerance management requirements are not sufficiently covered by today's product and production development processes. The following approach presents a solution to grant a domain spanning collaboration between product development and production development with fully embedded tolerance management capabilities. Again, the approach is subdivided into a process, an IT and a methodical part.

2.3.1 Process approach
To ensure a smooth simultaneous engineering process it is necessary to give an adequate feedback on changing product and production information just in time. Therefore, the build-up process for the required simulation models has to be highly efficient and as quick as possible. This means the main focus has to be put onto an automated tolerance simulation model creation for dynamically changing product and process-data. Such a model-based process is currently being developed by the authors and described in detail in [6].

2.3.2 Tool/IT approach
The focus of today's PDM systems is on organizing product data [5]. For cross-domain product and production process related data (e.g. assembly graphs for several vehicle configurations or production locations), no adequate solutions are available, yet [7]. The implementation of an extended development environment using one integrated data management system seems to be a solution. This is why the focus of attention should be put on developing the extended development environment based on an integrated data management system for storing and handling product and production process related data, together. This possibility of storing tolerance management specific knowledge supplements the standardized tolerance simulation model described above and offers efficient solutions such as tolerance simulation templates.

2.3.3 Methodical approach
Nowadays, in the product and production development process all the required information to set up a tolerance simulation model is available [6] and can be stored in a neutral exchange format. Once the development data is digital available in a standardized format, new algorithms can be developed to take-over the time consuming (manual) simulation model build-up process. The main challenge is however to map the experts' knowledge in these algorithms to ensure a correct simulation model build-up. Tested algorithms ensure a less fault-prone model build-up and improve the quality of the simulation results.

3 Change management across product and production development

Change management for both products and the respective production equipment plays a key role regarding high quality in production planning and production launch. For highly automated production plants, e.g. in automotive body in white production, the information about changes and their technical and economic effects (e.g. joining technologies, quantity structures, costs, production dates etc.) is quite complex to manage. Due to shortened development and production cycles in the automotive industry, requirements to current change management methods are rising. As a matter of fact an ineffective change management process leads to severe trouble at the start of production (SOP), especially to additional costs and quality issues.

3.1 Situation today

Dealing with changes at an early stage of the product development cycle is different than to a product with a high maturity level. In the early, **conceptual phase**, the relocation of a weld point might be negligible, since only the quantity of weld points matters. However, towards the SOP, i.e. in the **component design** and **system integration** phases, a single relocation of a weld point affects product development (e.g. costs, strength etc.) as well as production development (e.g. clock cycle, accessibility, reprogramming).

To increase the quality of production planning an effective change management process has to include product development and production planning as well as internal and external suppliers. This process chain between the placing of production plants and the SOP with all participants is the most complex in the whole product creation process (e.g. relocation of a weld point in the product requires new simulation about accessibility and reprogramming of robots, which is mostly done by external suppliers). Therefore it is virtually impossible for the designer of a product to anticipate all consequences of a change.

Due to shortened development cycles, the maturity level of perspective products is low at the start of plant engineering. This implies that more and more changes have to be managed, especially during the manufacturing of hardware components of plants and before SOP, which is critical regarding costs and quality.

After the SOP, the body in white is generally not changed. As a special requirement, replacement products may have to be manufactured by existing production lines. This is a special challenge for change management since plant documentation must be on an up-to-date level, then. Mostly however, there is no complete feedback to CAD data about changes made in plants during manufacturing time.

3.2 Deficits

Further investigating change management between the placing of production plants and the SOP brings up the following deficits regarding processes, tools/IT and methods.

3.2.1 Process deficits

There are several standard procedures defined in literature for dealing with changes [8, 9], and standard workflows in large scale enterprises exist. Often there are periodic cross-domain meetings with participants from product and production development. Due to crowded schedules it is not always possible for all relevant parties to participate. Additionally, the number of changes is high, and getting an overview about all changes is time-consuming. With growing maturity of the production plants, changes concerning them are only evaluated by plant engineers, which are mostly external suppliers. In some cases, this requires many steps (e.g. tracking of change process, data transfer, etc.), what is also time-consuming (days to weeks). Consequently, regarding production tests, the change might not be implemented in time to the assumed production test date.

Additionally, changes occurring are “pushed” by product development. There is no push/pull mechanism in a way that production development is able to systematically initiate a change.

3.2.2 Tool/IT deficits

As shown in section 2, the development environment has separately grown for generations. There are comfortable tools for product change management [10] – within or outside of PDM environments, but not sufficiently including the whole process chain concerning changes made in body in white parts. Consequently the workflow for a change is interrupted, which leads to higher documentation efforts in production development. Often there are still secondary paper-based workflows to deliver change information to suppliers. Neither there are workflow-based IT-tools nor common PDM-backbone for product and production data. Especially the documentation of joining technology in product development PDM-system is not matching to documentation requirements from product development.
In addition to workflow-systems there are reporting systems – generally not focused on one domain, but mostly using information from workflow-based tools. Hence these tools are able to report process changes, e.g. “release confirmed”, but missing user specific information about what changes in the product on a technical level. This still depends on user specific documentation hence there is no sufficient interface to PDM-systems.

3.2.3 Methodical deficits

As a method to deal with changes there are standard workflows including different standard steps and releases due to e.g. compliance, audit security etc. During product and production development there is a growing lack of time with the result that period of the technical implementation of a change contradicts standard workflow procedures.

3.3 Approach

An approach for change management has to deal with a lot of users, processes, IT-solutions and methods. Therefore, an integrated approach for change management considering both product and the respective production development has to take process, tool/IT and methodical aspects into account.

3.3.1 Process approach

Cross-domain workflows including product and production development as well as suppliers have to be defined and established. Especially the initiation of changes on both sides has to be provided.

3.3.2 Tool/IT approach

A consistent data-backbone integrating product and production development is needed. This requires involving external partners. Since external partners have limited access to confidential product data, an interface from the product change management system to a separate supplier exchange server application could be a solution, but would probably need additional data from other, e.g. ERP systems (e.g. date of production). By realizing that interface reports might be used to control the process. Also a new concept for change management in PDM systems is needed concerning external partners. An integrated database with changes as data objects compliant to enterprise processes’ is necessary.

3.3.3 Methodical approach

Standard workflows have to be adapted to required periods of time needed by the technical implementation of changes. If necessary, projects have to be reorganized by still granting compliance as well as audit security, but reducing efforts e.g. during the evaluation of changes concerning costs. An entire cost package for changes for each project could be a solution.

4 Integrated Eco-Engineering

Due to stricter environmental regulations and rising energy prices, companies have to focus on reducing the environmental impacts of their products and resulting production. Both product development and production development consider this target, but they handle environmental aspects more or less independently in their processes. A deeper integration of both fields provides a huge potential for a more comprehensive reduction of environmental impacts.

4.1 Situation today

In the field of environmentally oriented product development – ecodesign – impacts on the environment are considered during the development phase of the product in order to generate environmental-friendly products [11]. Especially, the early phases are of an outstanding importance, as the environmental impacts of the whole lifecycle of the product are primarily defined at this time. There are a lot of different tools aiming at the assessment and improvement of environmental impacts, focussing different stages of the lifecycle. For example, a lifecycle assessment summarizes all impacts on the environment – inputs and outputs – over all phases of the product lifecycle and assesses them in order to detect potentials for improvement [12]. There are different kinds of checklists and environment oriented tools such as QFD or FMEA derivatives. All impacts on the environment of the production system lifecycle are also to be considered, as a subset of the manufacturing phase of the product. The characteristics that are set in product development influence the production at a high proportion, as the production development is driven by the product to a very high percentage. Environmental impacts are often only considered when the production system is already built up. There are different tools and methods to optimize the interaction of the production system in order to save i.e. energy or material input.

As an example, again an automotive body in white example is analysed. In **conceptual design**, the joint technology is predefined in the conceptual phase by product development. Production development has to fulfil the resulting requirements. Changes of characteristics are generally only proposed, if they are not producible. By selecting the joint technology, environmental impacts of the later manufacturing are primarily determined. Welding of metal could be replaced by clinching or adhesive bonding in order to change the impacts. In addition, the rough process sequence for the later production that also influences the environmental behaviour depends on the conceptual design. In the **component design** phase, the number and position of the joint points are equally predefined by the product development and only influenced by the production development, for example if the accessibility is not ensured. Energy related changes should also be enabled in this phase. Furthermore the later amount of inspection in the production just as the detailed process sequence is also influenced by the characteristics that are set in the component phase of the product development. During **system integration**, detail information from all components and manufacturing processes are needed for an overall simulation model of the production environment. In this phase, only improvements of the environmental impact without any influence on product characteristics are allowed. For entire assessments, data are taken from general databases or measured on the previous production system or plant.

4.2 Deficits

An integrated Eco-Engineering is currently suffering from the following circumstances.

4.2.1 Process deficits

Both processes are executed in parallel, but only synchronized over common milestones. The production development is driven by the product and has to adjust the production to the product characteristics. The production development is restricted only to request changes in critical cases. Changes that would lower the environmental impacts are normally not considered. The production system is developed or adjusted to manufacture the required product characteristics. In contrast, there are some concepts to develop a product for an existing manufacturing system (e.g. [13]). This may avoid the building of a new plant, but environmental impacts during lifetime may be higher than by applying the newer technologies. For this reason, only an integrated view on both the product and the plant can enable the lowest environmental impacts.

4.2.2 Tool/IT deficits

Tools, like life cycle assessments that take all processes concerning a product into account are based on general databases with exemplary processes. Detailed data from own manufacturing processes have to be added. These data are not simulated but measured for the previous production plant. Additionally, both domains use different kind of software tools, classical CAD on the product development side and software from the digital factory on the production development side, that are partially working on different databases [14].

4.2.3 Methodical deficits

A lot of methods in product development support the user to select product characteristics (often material) that cause lower environmental impacts in the manufacturing phase, e.g. [15]. These methods often suffer from a unilateral perspective with insufficient knowledge from production development, which is in contrast not allowed to change these characteristics. Methods in this field often only focus an isolated optimisation of the operating phase [16]. Integrated methods that consider both the product development and the production development domain do rarely exist.

4.3 Approach

An integrated Eco-Engineering that considers both processes, product and production development would be desirable in order to create more sustainable products. In the following paragraph, an integrated approach for the development of products that have lower environmental impacts during the manufacturing phase is presented.

4.3.1 Process approach

Both processes have to be further integrated and equated. Synchronization only over milestones is not enough; both processes need a deep linkage. In early phases, production development has to be enabled to assess the product concept concerning environmental aspects and should feed a general database with rough data about different manufacturing processes used or planned in the company. In an iterative loop the detailed characteristics of the product are being determined in collaboration with the focus on minimal impacts on the environment in the manufacturing phase beside other phases.

4.3.2 Tool/IT approach

Especially, in production development there is a need for an overall simulation tool that can estimate environmental impacts like the energy consumption as far as possible automated and in parallel to the design work. With models of the production system, the preliminary energy consumption in the manufacturing of different product concepts can be simulated and assessed. Furthermore environmental data about the developed product should be efficiently provided to the product development. PDM systems should integrate these data.

4.3.3 Methodical approach

Methods for an integrated consideration of environmental impacts like the energy consumption extend existing methods with an interface between product and production development. Different possible solutions that are worked out in the product development are assessed according to their energy consumption during the manufacturing phase. This assessment is executed by production development.

5 Conclusion and Outlook

The comparison of the product and production development domains presented in this paper shows similarities in principle, but differences in detail. These differences disturb domain-spanning processes and lead to inefficiencies in the overall product creation process. The three example integration areas presented in sections 2-4 show the need for and relevance of an integrated process approach for product development and production development. For each of the three areas, integration approaches have been described.

Comparing these approaches shows consistencies across the areas in main points. Thus, figure 2 proposes a consolidated integration approach. This approach considers aspects from multiple dimensions – process, method and IT dimension in the whole development process - divided into conceptual, component and system phase.

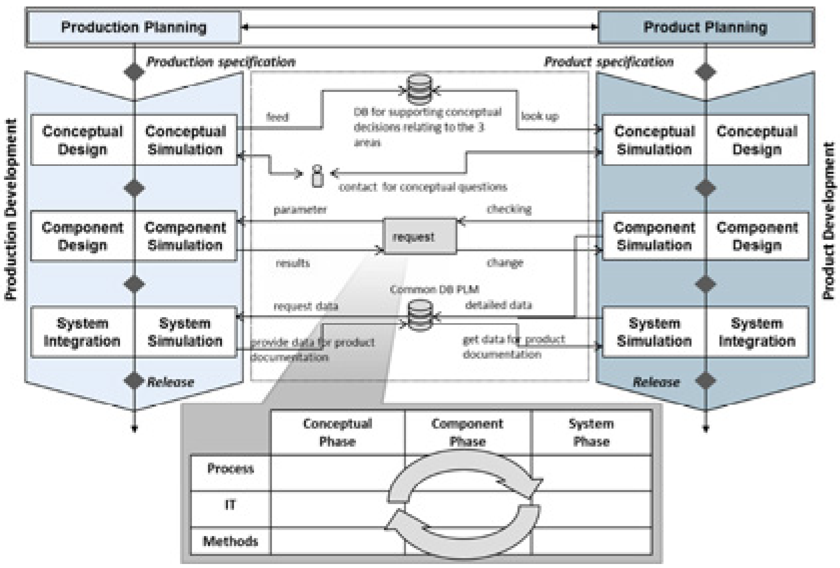

Figure 2 Aspects of an integrated product and production development framework

Through such an approach, quality issues arising from weak domain integration can be avoided, and optimization potentials on an integrated product and production engineering level – which may be superior to domain-specific optimizations – can be realized.

Table 1 gives examples for the integration aspects from figure 2 based on the findings from the three integration areas investigated. The integrated product and production development framework presented can serve as a basis for integration activities on a more detailed level. Further developments in the three areas described and in other integration areas will also lead to a further detailing of the framework's processes and further consolidated methods, providing also a basis for a further integration on a tool/IT level. It could, then, offer benefits through a higher and more efficient parallelization of product and production development processes.

Table 1 Example integration aspects

<table>
<tr><th></th><th>Conceptual Phase</th><th>Component Phase</th><th>System Phase</th></tr>
<tr><td>Process dimension</td><td></td><td colspan="2">▸ Accelerated, task-specific, cross domain workflows</td></tr>
<tr><td rowspan="2">IT dimension</td><td>▸ Template based simulation model build-up for storing simulation experts knowledge</td><td colspan="2"></td></tr>
<tr><td colspan="3">▸ Consolidated and/or integrated domain data model(s)
▸ Domain spanning database for storing product and production information</td></tr>
<tr><td>Methods dimension</td><td colspan="3">▸ Consolidated methods across domains
(e.g. automated domain-spanning tolerance simulation model build-up)
▸ Mapping of engineering data to simulation environment by tested algorithms</td></tr>
</table>

References

[1] Burr, H., Vielhaber, M., Weber, C., "Information Management for the Digital Factory – Bridging the Gap Between Engineering Design and Digital Planning", proceedings of International Design Conference – Design 2006, Dubrovnik, 2006.

[2] Vielhaber, M., Stoffels, P., "Product Development vs. Production Development", proceedings of 24th CIRP Design Conference, Milano, 2014.

[3] Burr, H., Müller, M., Vielhaber, M., "IMS – A Framework for Engineering Process Analysis", proceedings of the International Conference on Engineering Design – ICED 07, Paris, pp 355-356 (executive summary), No. 428, 2007.

[4] Bohn, M., Hetsch, K., "Toleranzmanagement im Automobilbau", Hanser-Verlag, Munich, D, 2013.

[5] VDI guideline 2219, "Information Technology in Product Development – Introduction and Economics of EDM/PDM Systems", Beuth-Verlag, Berlin, 2002.

[6] Litwa, F. M., Gottwald, M., Bohn, J. F., Klinger, M., Walter, S., Wartzack, M., Vielhaber, M., "Automated point-based tolerance analysis model creation for sheet metal parts", proceedings of 13th CIRP Conference on Computer Aided Tolerancing, Hangzhou, 2014.

[7] Eigner, M., Stelzer, R., "Product Lifecycle Management. Ein Leitfaden für Product Development und Life Cycle Management", 2nd Edition, Springer, Heidelberg 2009.

[8] Lindemann, U., Reichwald, R., „Integriertes Änderungsmanagement", Springer, 1998.

[9] DIN 199-4, „Änderungen", Vol. 10, Beuth-Verlag, Berlin, 1981.

[10] Schuh, G., Stölzle, W., Straube, F. „Anlaufmanagement in der Automobilindustrie erfolgreich umsetzen", Springer-Verlag, Berlin, pp 221-228, 2008.

[11] ISO 14006, "Environmental management systems – Guidelines for incorporating ecodesign", Beuth-Verlag, Berlin, 2011.

[12] ISO 14040, "Environmental management – Life cycle assessment - Principles and framework", Beuth-Verlag, Berlin, 2009.

[13] Smithson, A., Hamza, K., Saitou, K. "Design for Existing Lines: Part and Process Plan Optimization to Best Utilize Existing Production Lines", Journal of Computing and Information Science in Engineering, Vol.7, pp 126-131, 2006.

[14] Vajna, S.,Weber, C., Bley, H., Zeman, K., "CAx für Ingenieure", Springer-Verlag, Berlin, 2008.

[15] Luttrop, C., Lagerstedt, J. "EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development", Journal of cleaner Production, Vol.14, pp 1396-1408, 2006.

[16] Thiede, S. "Energy Efficiency in Manufacturing", Springer-Verlag, Berlin, 2012.