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ENERGY EFFICIENCY ORIENTED DEVELOPMENT OF PRODUCTION SYSTEMS

Stoffels, Pascal; Vielhaber, Michael
Saarland University, Germany

Abstract

Based on rising energy prices, stricter regulations of carbon dioxide emissions and a rising awareness for our environment, it is not sufficient to optimize energy consumption only during the utilization of products; production, including assembly, has to become more energy efficient, too. In order to reduce the energy demand, the later energy consumption must be considered early in the development of the production system. In these phases, characteristics that are responsible for the later energy consumption are predetermined. A methodology for the development of assembly systems that is aiming at energy efficiency is currently being developed by the authors. Both lifecycles, of product and the corresponding production system are examined and correlations worked out.

Keywords: Ecodesign, Sustainability, Energy Efficiency, Production (system) development, Design for X (DfX)

Contact:
Pascal Stoffels
Saarland University
Engineering Design
Germany
stoffels@lkt.uni-saarland.de

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1 MOTIVATION

Due to rising energy prices and stricter regulations on carbon dioxide emissions, an isolated consideration of single environmental aspects of different phases in the product lifecycle is not sufficient, any more. The consideration of the whole product lifecycle has to be introduced and environmental impacts along the whole lifecycle have to be decreased. Nowadays, environment-friendly products often target at a reduction of environmental impacts in the use phase, only. Impacts on the environment during manufacturing are either not focused on, considered from a too abstract perspective or improved reactively at the already existing production system. For comprehensive optimisations, product development and production development have to be addressed in an integrated way. The energy consumption is focused on by the authors as it can be seen representative also for other environmental impacts as long as energy demand is not fully covered by renewable energy sources.

Fully automated assembly systems, as a part of the manufacturing process, are addressed in this contribution.

Several approaches aim to decrease the energy consumption during production, when the assembly system is already built up. Additional energy savings can only be realized by considering the energy demand early in the development process of the plants, where characteristics that are responsible for the later energy consumption are predetermined. In today's planning of assembly systems, energy is often not in focus, but e.g. quality, costs and time which are potentially competing targets to energy consumption. Quality and time are untouchable, but costs may temporarily be increased, when energy savings are higher or the customer perception demands a greener production.

This research introduces a methodology for the development of energy efficient assembly systems. The methodology is applied on a model factory for the automated commissioning of vehicles (see figure 1). By moving commissioning steps into the continuous assembly line, cycle times in the test benches at the end of the line can be shortened, which results a reduction of the number of these test benches. Thus costs and factory space can be saved. The described assembly system targets an energy efficient operating in order to save further costs.

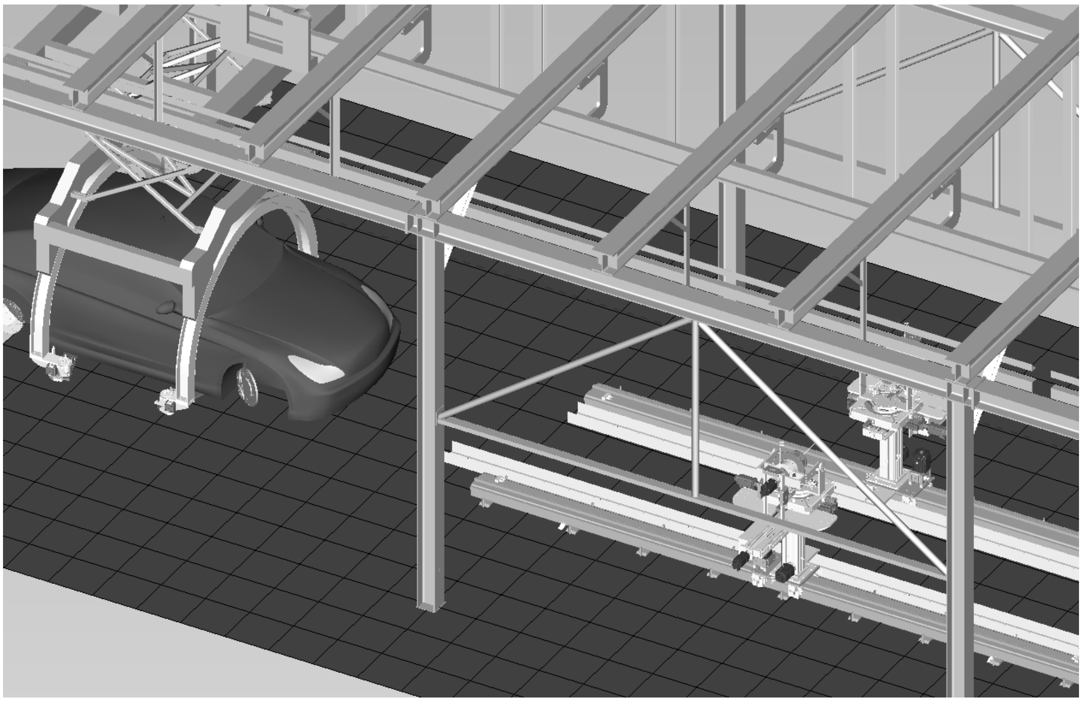

Figure 1. Assembly system for the automated commissioning of vehicles

In assembly systems, the energy efficiency is often increased during production breaks by using conventional approaches that switch the operating modes into energy efficient ones. In order to achieve further energy savings during the operating, Brett et al. (2012) examines and optimizes the kinematics of the assembly system. Furthermore, it is possible to improve the energy efficiency of the used components. Optimizing the interaction between these components can avoid load peaks to increase the energy efficiency (Putz et al., 2011). For saving even more energy, it is necessary to consider the production and assembly process within an integrated product and production creation process. An overall methodology that considers all these approaches is a useful tool for energy efficient assembly systems and currently developed by the authors.

For this reason, methodologies from environment oriented product design - EcoDesign - are applied on the development of assembly systems, focusing on energy consumption. Later on, other inputs and outputs and environmental impacts are going to be examined. The planning process for plants, according to the digital factory guideline VDI guideline 4499 (VDI, 2008), is taken as the basis for the development of energy efficient assembly systems for this research. Respective tools and software from the digital factory are integrated, in order to handle the complexity of the system.

In section 2, the current state-of-the-art for the fields production plant development, product development, EcoDesign, and energy efficiency in production is shown. In section 3 an integrated approach for the development of energy efficient assembly systems is described. A virtual model that allows the simulation of the energy consumption is needed to assess the lifecycle in early development phases. Finally, conclusions will be drawn in section 4.

2 STATE-OF-THE-ART

In this section the state-of-the-art of the different domains is described. The focus is on the process models and the IT-support.

2.1 Production system development

The VDI guideline 4499 "Digital Factory" (VDI, 2008) (see figure 2) provides a general planning process for production systems to production planners and developers of the production equipment. Three basic objects are introduced in the digital factory: products, resources and processes (PPR). This paradigm is used for all considerations. The production system as the resource manufactures the product in the process. The three objects are linked, depend strictly on each other and represent the environment of the factory. The VDI guideline 4499 (VDI, 2008) provides an abstract planning and development process for these resources. In this contribution the development of the resources for assembly is discussed and deeper examined.

The different domain specific development phases are executed in parallel to achieve a faster ramp-up of the system. Further development time savings are realized by a virtual commissioning of the plant. The maturity of the control software can be increased, collisions can be detected and accessibility can be ensured. For that reason the time for the real commissioning is shortened, due to the higher maturity of the whole system.

The characteristics determined in product development have a huge impact on the development of the corresponding production system. For this reason both fields are closely linked to each other. Gausemeier et al. (2010) proposes an integrated specification technique for mechatronic products and the production systems. The derivation of the production system structure out of the principle solutions of the products is shown. The principle solutions of the product determine the conceptual design of the production system. The results constitute the principle solutions of the production system. These solutions have to be substantiated in the next steps and integrated to an overall system.

An efficient development of production systems requires a virtual model of the system in order to ensure the predetermined properties and functions. Standard three dimensional mechanical CAD tools are not enough. Moving parts and the interaction with other components have to be simulated in order to check the functions of the system. Furthermore, a hardware-in-the-loop simulation of the programmable logic controller - also called virtual commissioning - has to be performed. For these tasks, tools like Tecnomatix by Siemens PLM Software (2014) or DELMIA by Dassault Systemes (2014) with additional software are commonly used, for example.

In the field of production it would be desirable to estimate the energy consumption of production equipment early in the development phase, for example by simulations. But nowadays only manufacturer of components simulate the energy consumption of their products, for example with mathematical models of the actor including the controller. Alphanumerical energy consumption simulations of the interactions of the different components in a factory are often executed, basing on fixed values for different states. The consumption of a component has to be measured costly, because the producer does often not know the energy demand.

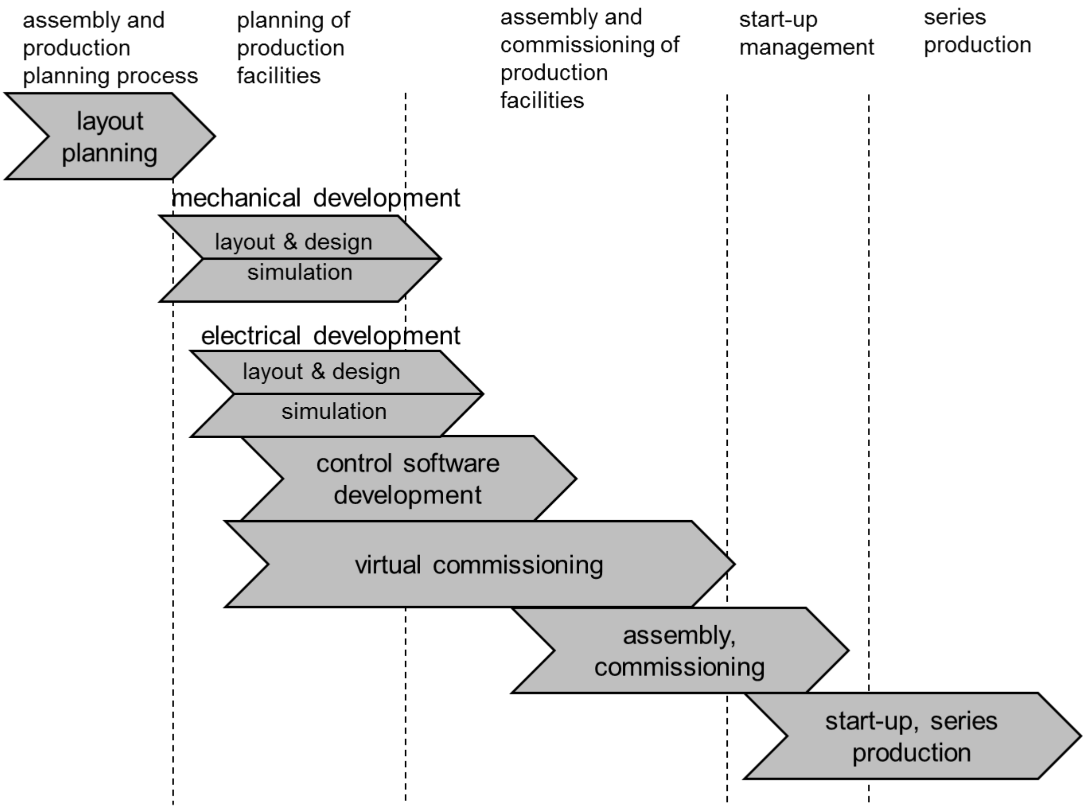

Figure 2. Planning phases of a production plant similar to VDI 4499 (2008)

2.2 Product Development

Design engineers are capable to use a lot of different standardized methods and approaches for the development of products. The VDI guideline 2221(VDI, 1993) provides a formalized, long established and recognized process model. The process is segmented into three phases: conceptual design, embodiment design and detail design.

Developing complex multi domain products - mechatronic products- requires a different approach. The VDI guideline 2206 (VDI, 2004) describes the development of such products. It is based on a V-model that starts with the system design phase. Afterwards in the domain-specific design phase, further detailing is executed in the appropriate domain, for example by applying the VDI 2221 (VDI, 1993) methodology. The results are integrated in the final phase - the system integration. The process is performed iteratively, depending on the degree of complexity, in order to get a suitable solution.

In product development a lot of different IT-tools exist to support the engineers. CAD software is an established tool to handle the complexity of products. Furthermore, CAE software is getting a standard in most companies to ensure required properties and functions based on different numerical simulation procedures.

2.3 EcoDesign

The ISO guideline 14006 (2011) defines ecodesign as the “integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle”. According to Diehl and Brezet (2005), the first implementations of EcoDesign, was re-design of existing products with the focus on reducing environmental impacts. In the last years additional approaches have been developed. Eco-Benchmarking compares products of competitors to the own product and transfers knowledge in order to reduce the environmental impact. Eco-Innovation enables new evolutionary products with fewer effects on the environment, by using ecologically oriented methodologies in the development phase (Diehl and Brezet, 2005). The difficulty of the application increases the earlier it is applied in the development process. As an example for Eco-Innovation, an approach to reduce the later energy consumption of vehicles by using a mechatronic system simulation in early development phases is shown by Dohr et al. (2013). The level of detail of

the results is reduced by using simplified calculations that allow more unknown parameters but provide enough significance to support conceptual decisions.
For realizing really environment-friendly products the system boundaries of the considerations have to be adjusted, in order not to neglect relevant phases. A comprehensive lifecycle assessment (LCA) is needed, to evaluate different product concepts to determine the one with the lowest impact on the environment. According to ISO 14040 guideline (ISO, 2011), all inputs and outputs and the environmental impacts of the system have to be considered and evaluated. The cumulative energy demand (CEA) represents a limitation of this assessment to the consumed energy along the lifecycle (VDI, 1997).
One possibility to consider environmental impacts in the design process is an environmentally oriented Quality function deployment (QFD). Akao's (1990) QFD method translates the "Voice of the customer" into technical product or process specifications. Several Extensions of these methods in direction to EcoDesign have been raised and are listed and compared by Schendel and Birkhofer (2007). One of these approaches is shortly introduced.
The QFD for Environment (QFDE), according to Masui et al. (2003) adds an "environmental Voice of the Customer" and environmental engineering metrics. Designers have to consider this input to integrate environmental aspects in the development of the product. This method is a powerful tool to reduce environmental impacts of products.
Different software tools for the lifecycle assessment are available to support the analysis of the environmental impact of products. Ostad-Ahmed-Ghorabi et al. (2009) describes an approach that integrates a simplified lifecycle assessment into CAD. It improves the Re-Design of products or the design of a product that is part of a product family, because data for a comparison are essential for this approach. Based on this data and user defined values like for example power, material and data like weight and volume, derived from CAD, an estimation of the environmental impact can be performed. The normal LCA process needs a complex model and a lot of input data, but simplified approaches with predefined processes are also available but do not provide so detailed results. The approach is limited to the redesign of products and the development of similar products of a product family, but generates time and costs benefits.
Design for Environment is an equivalent term for EcoDesign. Design for sustainability often encompasses social aspects, in addition.

2.4 Energy Efficiency in production

The ISO 50001 guideline (ISO, 2011) defines energy efficiency as the "ratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energy". A method to increase the energy efficiency of existing production systems is a material flow simulation combined with an energy flow, which is described by Putz et al. (2011). The interaction of the components of the production system has to be modelled for the simulation. For planning new production systems, energy data are taken from previous systems or estimated.
The software tool Plant Simulation by Siemens PLM Software (2014) supports these research activities. With the described method load peaks can be detected and avoided, what may result in a higher energy efficiency.
Brett et al.(2012) focuses the optimization of handling systems - as a component of the assembly system. A reduction of energy transformation steps caused by modified kinematics, the energy efficiency is increased. Another method that enables a reduction of the energy demand of the production system, is switching the operating modes into more energy efficient ones, for example during production breaks. For this task, Priced Timed Automata are used by Stoffels et al. (2013) to describe the system. These models can be simulated to get the best strategy for operating the production system.
A further approach for reducing energy consumption in production is presented by Lind et al. (2009). The SIMTER approach combines an analysis of the impact on the environment together with a discrete event simulation and a virtual analysis tool to evaluate the level-of-automation linked with ergonomic studies (Heilala et al., 2008). This method is used in the planning phase of production systems. Required data like material or material flow are derived from visual components and processed in an Excel tool for evaluating the system.

3 DEFICITS

A lot of methodologies for saving energy in existing assembly systems are established, but most of them are applied on already existing systems. The consideration of energy concerning aspects early in the development phase is often not performed. Comprehensive savings are only realized by an early integration of the aspects into the processes. In general, production development is described in a very abstract perspective and is not as well standardized as product development. Here a lot of different methods and standard process models just as comprehensive software support are available.

Environment-friendly product design - EcoDesign - is also a well-researched field. The number of available methods is high and the integration into the development process is advanced. For this reason, it makes sense to learn from EcoDesign for products in order to generate production systems that have low impacts on the environment.

In this research, energy consumption which has a huge impact on the environment, is primarily focused on, similar to the cumulative energy demand (VDI, 1997). In further work other inputs and outputs of a lifecycle assessment will be included, too.

The assembly system itself – as the resource of the assembly process – can also be considered as a product. So it is generally possible to apply methods from product development, but the requirements and constraints are different in contrast to common products. The approach depends on the view on the system. A manufacturer of assembly systems with a higher number of pieces, for example test-benches for suspensions or breaks, is able to develop them according to a product development methodology, but perhaps has to adapt each system to the later operating range in the customers factory. If an Original Equipment Manufacturer (OEM) or its supplier develops a new assembly system, it closely correlates with the assembly process and thus may be difficult to be designed by a product development method, especially because there may be additional organizational units that finally design and build the equipment. A detailed comparison of both fields – production development and product development – has been performed by Vielhaber and Stoffels (2014).

4 APPROACH

The assembly system is a mechatronic system, including mechanical, electrical and software components. The VDI guideline 4499 (VDI, 2008) provides, as the systematic embodiment design of technical products - VDI guideline 2223 (VDI, 2004) does, a suitable process model for the development of such systems, but it is very general.

A virtual model is essential for an efficient development of assembly systems. Basing on this model, the assembly process is simulated and visualized. The advantage of using such virtual models in the development of production systems is the detection of collisions between the installed components securing of the required properties and testing of the desired functions of the systems. Furthermore the communication with the customer or other divisions of the company is improved and the understanding of the task and implementation is clarified. The described advantages avoid large iteration cycles for change implementation at late steps of the development process. Changes and adjustments are moved to earlier phases, which results in less time delay and cost. The virtual model of the production system enables an evaluation of the energy consumption during utilization by performing special simulation methods, additionally. Beginning with the product development, the rough constraints to the assembly system are determined. The production development has to adapt the input from these early product creation phases, unless they are applicable. The assembly technology, defined in the product development, directly determines the planning phase of the assembly system. A common database that contains general energy data of different assembly processes which is provided to the product developers allows the selection of energy efficient manufacturing processes. Different rough concepts have to be compared to each other and evaluated according to environment aspects among other inputs like quality, costs and time. The methodical support is currently not sufficient enough and should be improved by introducing for example modified checklists and other evaluation tools.

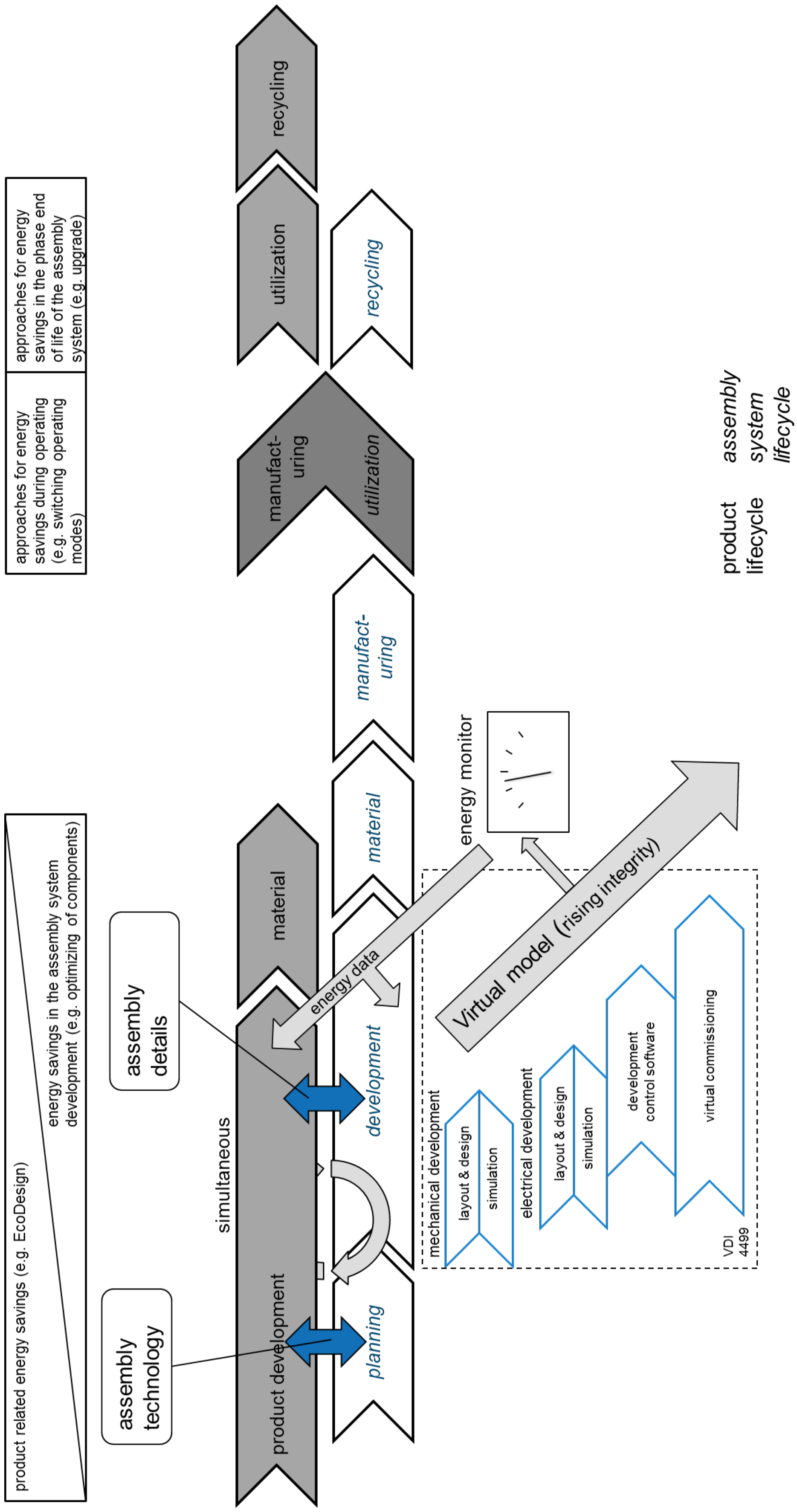

Figure 3. Development process for energy efficient assembly systems integrated in the lifecycles of product and production system

In the following phase of the product development, in the detailing phase, assembly details, like for example the number of welding points or the amount of inspection tasks, affects the domain-specific development steps of the production system, as well as the later energy consumption in its utilization phase. For this reason, evaluation tools have to be developed in order to optimize the product details according to the energy consumption in manufacturing. The challenge is not to neglect other constraints like quality, cost and time. A multidimensional consideration is inevitable for competitive overall solutions.

Approaches that aim at the design of robust products are suitable to avoid huge inspection scopes in the later final production steps. The results reduce inspection tasks or enable a complete removal of some steps. Besides the energy savings of the inspection, the number of test benches could be reduced which saves the energy for the manufacturing of the test benches.

As shown in figure 3, the integrity of the virtual model of the assembly system is raising with the development progress of the production system. Starting with a rough concept of the assembly system, containing previous components and processes, the model is getting more mature. The system gets more and more concrete. Process simulations are executed to get an optimized solution for step sequences, actions of the assembly system and placements of the components.

From a certain maturity level, it is possible to simulate the energy consumption of the just developed production system and provide it to the product developer. These simulated energy data become more exact over the time than data from a reference or previous process.

In a high automated assembly station, the interaction of the different components demands a lot of knowledge for the control software development, in order to create a process that fulfils the required tasks and functions. In this case, simulations of the control software code in a virtual environment of the system (Virtual Commissioning) play an important role in order to increase the quality of the control program before the commissioning of the system in the factory. Furthermore, it is possible to use such a simulation for evaluating the PLC code according to the energy consumption of the system. Inefficient moves of actors, for example too long paths, increase the cycle time and cause higher energy consumption. Such processes have to be detected and avoided when developing energy efficient assembly stations. In the case that the energy demand of the assembly phase is not significant in contrast to other stages of the product creation process, the product developer is allowed to neglect this phase and focus on other phases. Nonetheless the development of the assembly system has to continue considering energy efficiency, but both processes are not as strongly coupled.

Figure 3 depicts the process model for the development of energy efficient assembly systems integrated into the lifecycle consideration of product and production system. By improving the lifecycle impacts on the environment of the assembly system, the lifecycle impacts of the assembled product are also decreased.

5 CONCLUSION AND OUTLOOK

The field of product development is a well-supported field in engineering concerning different process models, methods and software tools. In contrast production development has to cope with a lower support that is currently rising. Furthermore, reducing environmental impacts is often more in focus of product development (targeting the use-phase) – than of production development – (targeting the production phase). Already existing production systems are often optimised reactively during production breaks, in the context of management inputs.

The focus of the current research is on the energy consumption that results in certain environmental impacts today. Later on further aspects of a lifecycle assessment will be considered, too. In several cases the energy consumption of existing assembly systems is reduced; for example by using methods that switch components that are not working because the production is interrupted, to energy efficient states. A further approach to save energy in the production detects load peaks in order to avoid them. The presented research takes the whole development process of new assembly systems into account. By improving the lifecycle impacts of the assembly system, the lifecycle impacts of the assembled product are also improved. The approach, basing on the VDI guideline 4499 (VDI, 2008) for developing production equipment, is shown in figure 3. An energy efficient assembly system can be developed in cooperation with an energy monitor that displays the calculated energy consumption. With suitable methods from the field EcoDesign combined with approaches from energy efficient production, an assembly system that consumes less energy is achievable. By information exchange of

energy data from assembly processes with the product development, even more benefits can be generated.
In the planning phase, the assembly technology, for example adhesive bonding or welding, determines the later energy consumption in the process to a high degree. In the further product development phase specifications, like inspection time or the amount of inspection are determined and have to be overtaken to the system. The assembly system development can redirect information about the calculated energy consumption to the product development that can execute a lifecycle assessment basing on this data.
In future research activities, the presented methodology will be further detailed and validated on the use case of the presented automotive assembly system.

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