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

An Initial Approach for the Application of Product Assembly Information in the Early Phases of the Product Development Process by Using Methods of Model Based Systems Engineering

Martin Eigner[1], Joscha Ernst[2], Daniil Roubanov[3], Thomas Dickopf[4]

Institute for Virtual Product Engineering, University of Kaiserslautern, Germany
[1] *eigner@mv.uni-kl.de*
[2] *joscha.ernst@mv.uni-kl.de*
[3] *roubanov@mv.uni-kl.de*
[4] *thomas.dickopf@mv.uni-kl.de*

Abstract
In this paper an initial approach is presented that supports the exchange of assembly-related information between design and assembly planning even before the geometry of the individual parts will be developed. For this purpose the concept of Product Assembly Information (PAI), as a method for an early time estimation, is transferred to the logical level of Model Based Systems Engineering (MBSE). To demonstrate the proposed method the paper focuses on expanding existing modeling constructs by relevant behavior elements capturing assembly relevant information.

Keywords: Model Based Systems Engineering, Product Assembly Information, Product Development Process, System Lifecycle Management

1 Introduction

To remain competitive on the market enterprises in high-wage countries must reduce overall costs and time-to-market but still have to deliver the same or better quality, reliability and more functions. Even though many of these factors occur during production, they are already defined during product development. Therefore optimization approaches have to focus on those two phases and should enable the exchange of information as early as possible.

This set of problems is addressed by the research project Pro Mondi which uses tools from Digital Factory and Virtual Product Engineering to reduce the gap between product development and assembly planning as part of production. During the project the so-called Product Assembly Information (PAI) [1] and a concept for sharing PAI along the PDP [2] were developed. The PAI defines assembly time-relevant information which is specified by product engineers and relevant for sharing with assembly planners. These approaches are suitable to reduce overall costs and time-to-market. However, they start with a (unfinished) CAD model and are therefore applied during the design phase. To achieve even better results this concept should be extended to earlier phases of the PDP.

One possibility is the use of the so-called Functional Product Description (FPD) [3]. FPD is a pragmatic approach based on the paradigm of Model Based Systems Engineering (MBSE) which enables an early model-based and structured product description by representing the core of a product definition. Thereby information artifacts and model elements are differentiated between requirements, functions, logical solution elements and physical parts to ensure traceability of requirements.

2 Methods

The paper applies the Product Assembly Information (PAI) as a method for an early time estimation to the logical layer of Model Based Systems Engineering (MBSE). By combining these two methods, assembly information can already be described in an early system model and thus support the System Lifecycle Management (SysLM) [4]. But first of all a short overview of existing PDP-models and there optimization potentials is given.

2.1 Classical product development process (PDP)-models

The classical product development processes (PDP) as described in Pahl et al. [5], VDI 2221 [6] and French [7] consist of successive phases. Each phase generates the input for the next one and the information exchange is placed at the end of each phase. Therefore, possible errors are discovered only at the end of a phase. This leads to time and cost-intensive iterative loops between two phases or even between two departments [8].

To speed up the product development Andreasen and Hein [9], Ehrlenspiel [10] and Ponn and Lindemann [11] suggest a parallelization of the phases in there PDP-models. These approaches are known as Simultaneous and Concurrent Engineering. They allow an earlier information exchange between different phases and are therefore also suitable to reduce the number and time needed for engineering changes.

Yet one step further goes the VDI 2206 [12]. The V-model for mechatronic products has a global cycle and each step in this cycle has many further iterative steps. For each function it has to be proved, whether the requirements are fulfilled, but it does not describe any details regarding the amount and time of the data exchange. For this purpose, concepts and methods have been developed during the research project “Prospective Determination of assembly work content in Digital Factory (Pro Mondi)” which are briefly described in the next chapter.

2.2 Early time estimation with Product Assembly Information

As part of the research project Pro Mondi concepts and methods for an early assessment of assembly time are developed. Those first time estimations are already performed at a very early design phase. With progression of the design process the accuracy of time estimates also increases.

Already during the first draft of a component in a CAD-System the designer himself may conduct a preliminary analysis of the assembly time. For this purpose he uses the PAI Wizard, which is integrated directly into the CAD-System. The wizard reads already defined assembly relevant attributes from the CAD model, such as the main dimensions of the component or the weight (calculated from the volume and density of the given material). [1; 2]

In a next step, the designer may define the connection between two (or more) components in the PAI wizard. Depending on the detail of the design, the accuracy of the connection definition varies. While in an early stage he only specifies that two components are connected, he could add more details later (e.g. the torque of a screw connection). In addition assembly difficulties like “obstructed view”, “limited tooling space”, “heavy components” and so on, can be specified [1]. Based on all this information, the PAI-assistant performs an analysis of the assembly capability. The result is displayed on the screen as an early feedback on the assembly suitability for the designer.

Once the design is satisfactory, a workshop is conducted. The previously by the designer himself performed analysis is verified in this workshop and adjusted if necessary. Therefore assembly planner and product developer come together. Only when this step is successfully completed, the optimized CAD-model including PAI-Container is passed to the work preparation.

2.3 Model Based Systems Engineering

Model Based Systems Engineering (MBSE) is a multi-disciplinary engineering paradigm that supports analysis, specification, design and verification during system development by propagating the use of models instead of documents [13]. Systems Engineering as such, comprises technical but also management processes and supports a balanced system solution in regard to various stakeholders [14]. Both the System Engineering, but especially Model Based Systems Engineering are methods that are suitable to reduce project risks at an early stage.
In previous work done at the Institute for Virtual Product Engineering [15; 3], a methodical guideline for the use of the Model Based Systems Engineering paradigm has been developed and is presented in Figure 1.

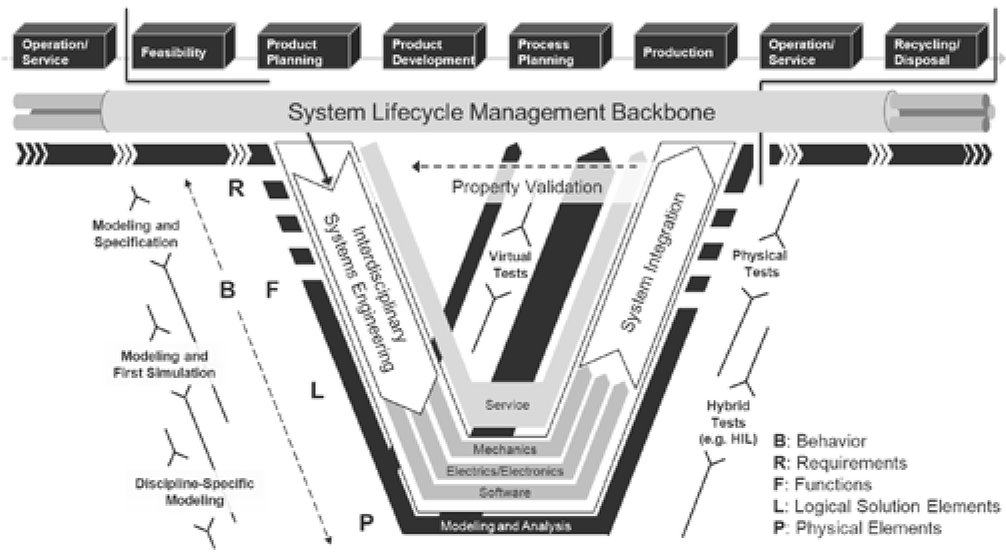

Figure 1: Extended V-Model for Multi-Disciplinary Product Development (based on VDI 2206 [12], adapted from [15; 3]).

With regard to the V-Model from [12], the extended V-model provides a model-based and structured system description in the early design phase on the left wing of the 'V'. The left wing is structured in the three overlapping levels of specification, first simulation and discipline-specific modelling. Thereby the information artefacts or model elements are differentiated in requirements (R), functions (F), logical solution elements (L) and physical parts (P), which are modelled in authoring tools and languages. Parallel to this, the behaviour (B) of the system and the user's behaviour are modelled and taken into account during system development. [4]
Semantic links between different model elements, as well as between elements of the same type, ensure 'horizontal' and 'vertical' traceability. Linking system elements hierarchically above different system levels permits 'vertical' traceability. 'Horizontal' traceability over the different system specification stages is achieved by the allocation links between different model

types (R-F-L-P) [3]. Figure 2 describes the traceability of assembly information along RFLP schematically.

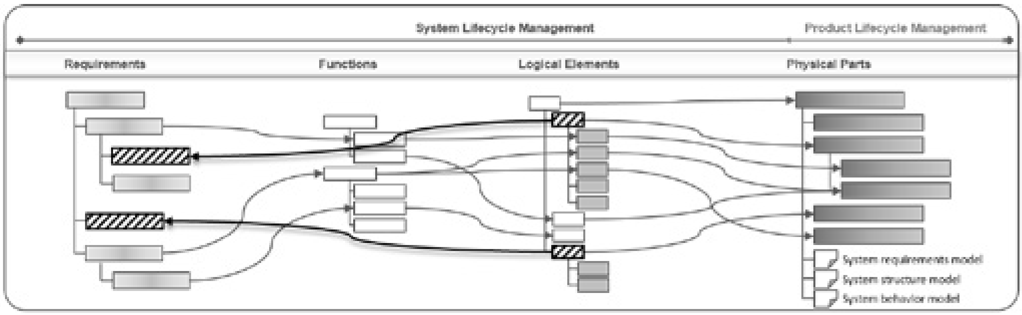

Figure 2: Schematic Representation of Assembly Information Traceability along RFLP (adapted from [3])

3 Initial Approach

The specification of the system model by structure elements in the early phase is too coarse for an early information exchange between product and production system. In this context it is important to also consider assembly information in the early design phase and to provide traceability from the level of requirements to the level of physical elements. Based on a simple and abstract example of a Segway it will be shown how it is possible and helpful to consider assembly information in the system model already in the early phases of development by using Model Based Systems Engineering.

Assembly Information has no impact on the functionality of the product system. This means that assembly requirements are a type of non-functional requirements, which just have an effect on the logical system elements.

3.1 Methodology for the Application of PAI in the Early Development Phases

The method presented below is divided into four steps, shown in Figure 3, which are performed by the *Systems Engineering Team, Assembly planner* and *Product designer.* The Systems Engineering Team creates and administrates requirements, the functional and the logical structure. The members of the team are *Systems architect, Systems engineer and Requirement engineer.* Gilz [16] describes the roles and their tasks more detailed. Product designer develop the product and implement the required product functions according to the product requirements. Assembly planner is an expert for process, resource and assembly planning. Both support the Systems Engineering Team.

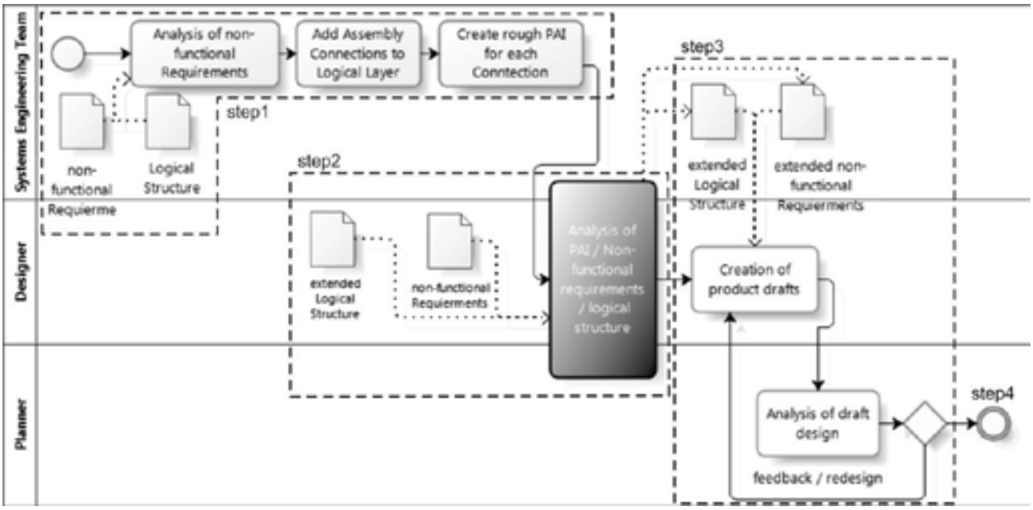

Figure 3: The process for the Application of PAI in the Early Development Phases

3.1.1 *Step 1: Analysis of Assembly Requirements and definition of assembly relevant connection*

The base for this step are non-functional product requirements and the logical structure of the product. The system architect analyzes non-functional requirements and identifies assembly relevant information. Based on this, he creates new assembly connections between the logical elements. Those connections show which logical elements are physically connected. Then the system architect extends each connection with rough assembly information from non-functional requirements.

3.1.2 *Step 2: Analysis and extension of assembly information by product designer and assembly planner*

In the next step the product designer and the assembly planner analyze the non-functional requirements and create further specifications of the logical layer. They have a different point of view and use their experience to add further assembly information.

3.1.3 *Step 3: Development of product drafts*

This extension of the logical layer and non-functional requirements is the basis for a discipline specific development. The designer creates the physical drafts of logical elements (the logical elements are subassemblies on the physical layer) based on the previously specified assembly information. He also discusses it with the assembly planner to choose one or more assembly options for further development. In parallel designer and planner determinate detailed requirements for the logical elements. If necessary this step can be repeated several times.

3.1.4 *Step 4: Generating Requirements for the Production System Development*

The product requirements, logical structure and product drafts can be used as basis for production system requirements and further development (Figure 4).

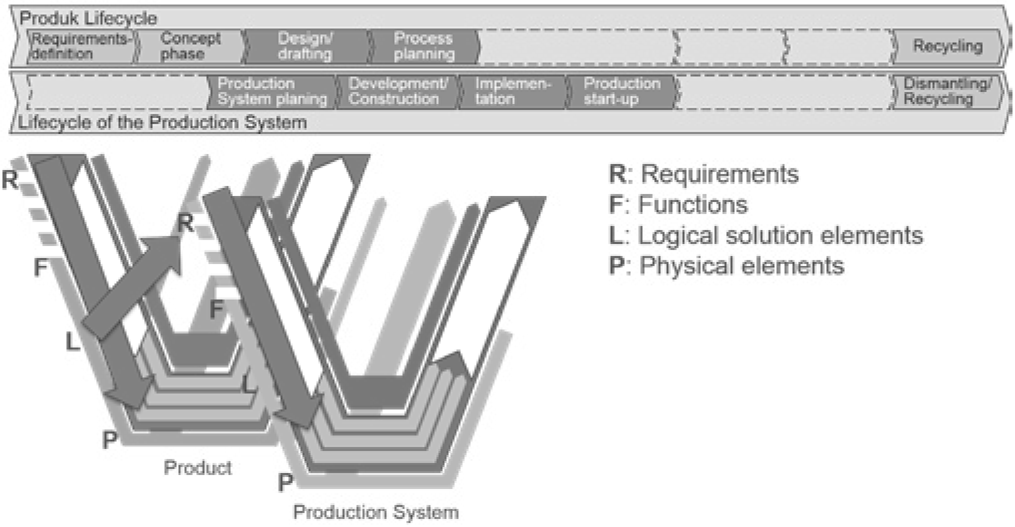

Figure 4: Information transfer from product development process to production system process

3.1.5 Expected benefits of the method

- MBSE approach enables better traceability of non-functional requirements of a product and assembly information in the early phases of development.
- Earlier assembly information exchange between different departments.
- The gap between product design and assembly planning can be reduced.
- Earlier development of production systems.

3.2 Case Study: Extension of non-functional requirements and logical structure of a Segway with PAI

This chapter demonstrates the method (described in chapter 3.1) with the logical structure of a Segway and some non-functional requirements. To reduce the complexity different flow types (like signal, energy etc.) between logical elements were removed from the model.

3.2.1 Step 1: Analysis of Assembly Requirements and definition of assembly relevant connection for a Segway

As described in the chapter 3.1 the systems engineer needs a logical structure and product requirements. Therefore he uses the System Definition Diagram (SDD) from VPE-SE-Profile, which shows external view of the structure and dependencies between the elements. The elements are in a "black box" representation with ports, but without connections between the ports. This diagram is based on a SysML Block Definition Diagram [16]. Figure 5 demonstrates a hierarchic logical structure of the Segway and some non-functional requirements of Wheel Carrying Elements.

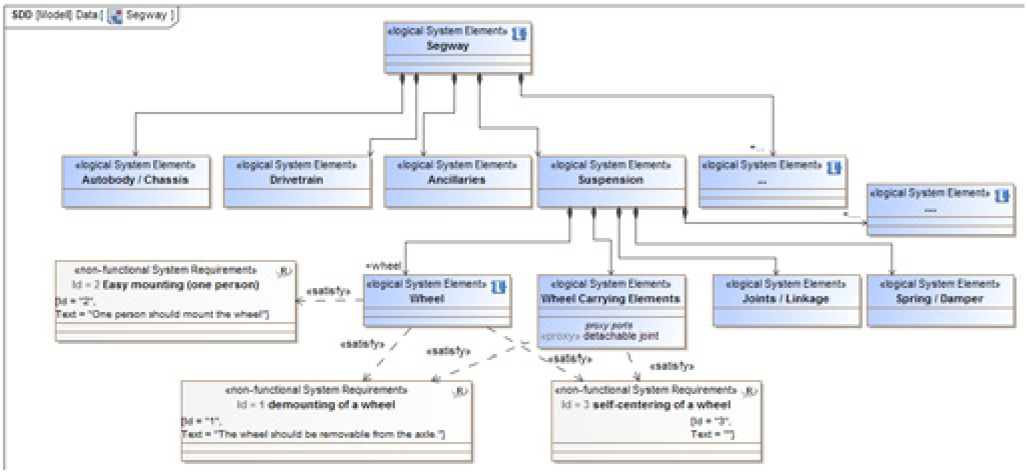

Figure 5: Logical structure and non-functional requirements

Although the structure is quiet abstract, yet some assembly connections can be created. The *Wheel Carrying Elements* and the *Wheel* should exemplify a creation of a connection. This assembly connection has to fulfill the requirements *demounting of a wheel* and *self-centering of a wheel*. These requirements determine the connection metadata. Figure 6 demonstrates the assembly connection with rough assembly information.

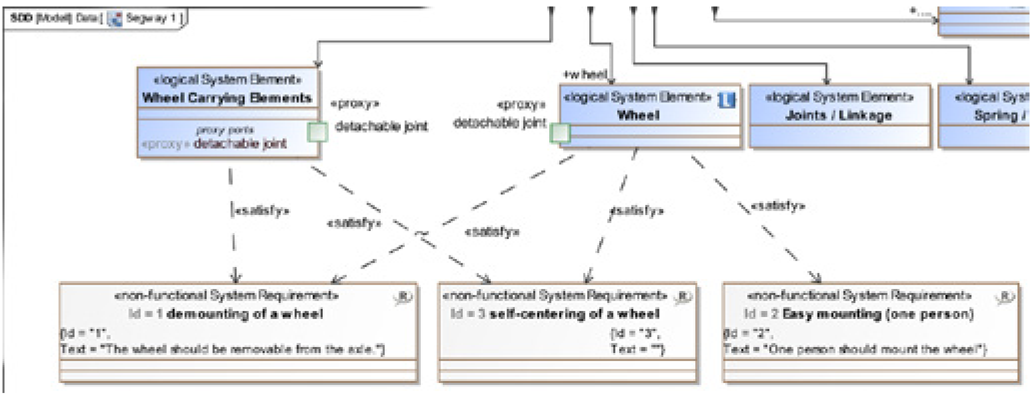

Figure 6: Assembly connection between Wheel Carrying Elements and a Wheel

3.2.2 Step 2: Analysis and extension of assembly information by product designer and assembly planner for a Segway

For further detailing the system architect gives the structure to the designer and assembly planner or arranges a workshop. The designer as well as the planner have a different point of view to the system architect. The first one searches for functions and their implementations. The second one analyzes the elements and looks for assembly possibilities. Both of them use their know-how to solve the tasks.

In our example, the designer analyzes which forces act on the Wheel connection, how much space he has for his solution, if the wheel has an interaction with the brakes, where is a position of the drivetrain etc. The assembly planner analyzes which tools he has for the assembling, how many workers can realize the connection, which problem he has with similar assemblies etc. New detailed requirements arise from the analysis and extend the requirement and logical structures. They are naturally not complete, but the designer can use them for draft design. An example of extended structures is shown in Figure 7.

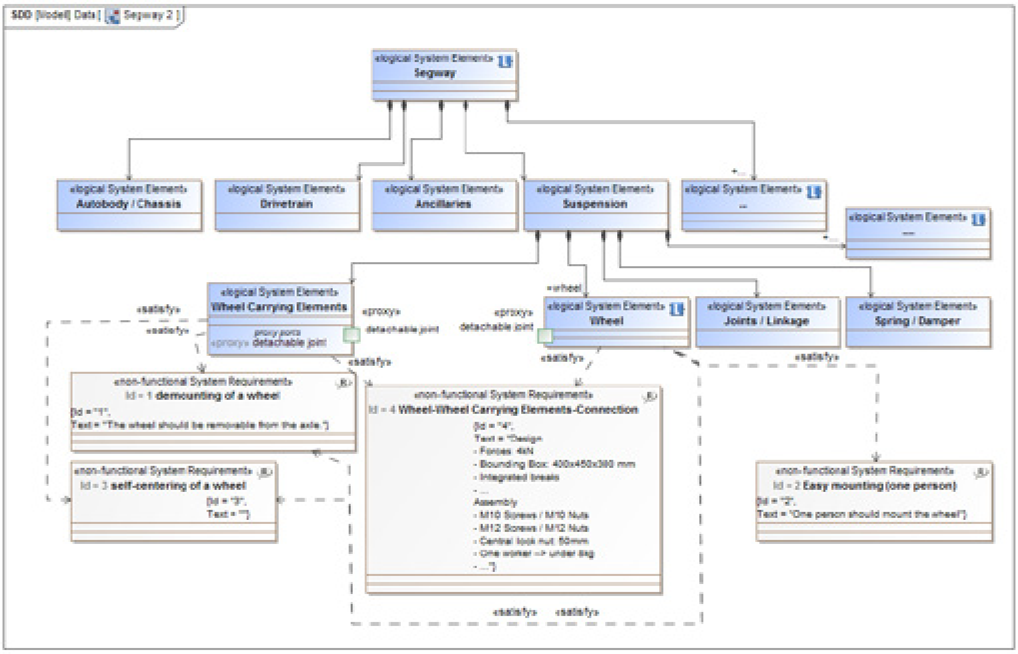

Figure 7: Extended logical and requirement structures

3.2.3 Step 3: Development of product drafts of Segway

Based on the second step the designer starts to detail the logical elements and to create physical subassembly and its drafts. In case of a wheel-hub-connection he can choose between a one lock nut and a more lock nuts concept. The next possible step is a decision about brake positioning. The first alternative mounts it on the wheel and the next one to put it on the hub. The created draft variants should be discussed with assembly planner and system architect. These steps are iterative and help to choose variant for further development. The Structure in Figure 8 represents one of many possibilities for logical structure extension.

3.2.4 Step 4: Generating Requirements for the Production System Development

As soon as one concept for the whole product is selected, it is possible to generate production system requirements. In case of the wheel assembly the production system should be able to put a tire on a wheel and must have tools to assemble brake disc and wheel. This information exchange is a good possibility for the production system planner to provide production system relevant requirements for the product. This step is not the focus of this paper and will therefore not be considered further.

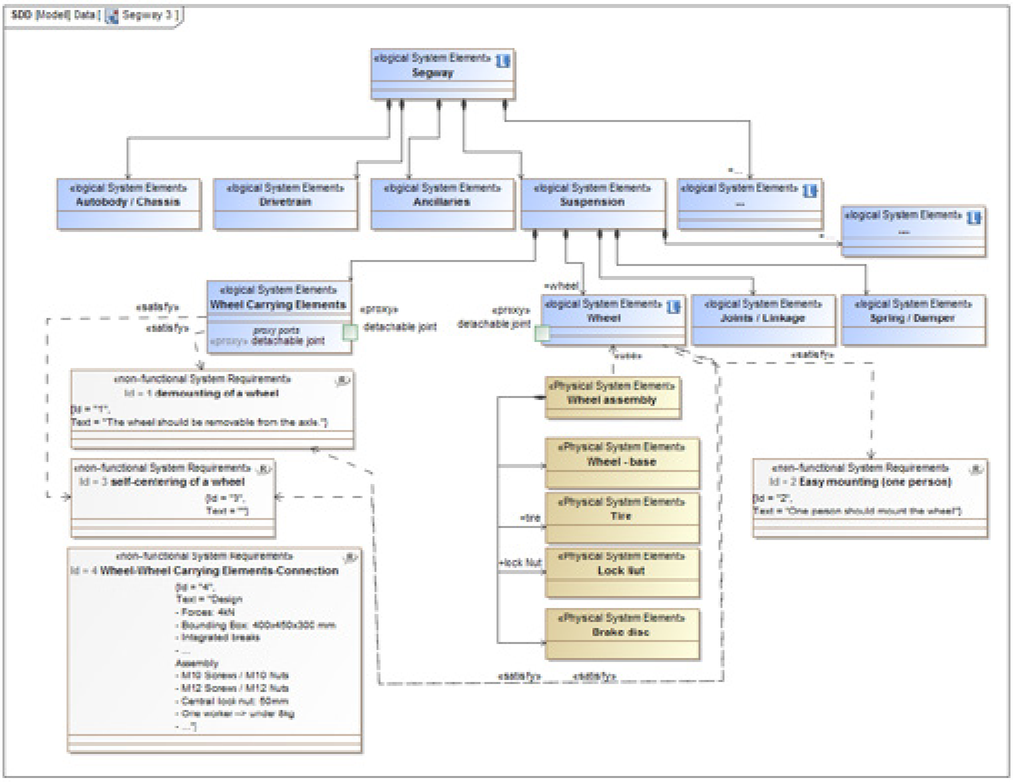

Figure 8: Extension of logical with physical elements

4 Conclusion

This approach enables an early assembly-relevant information exchange between product development and assembly planning already at the level of logical solution elements and reduces the systemic gap between both phases. By using MBSE assembly information is linked to their requirements and to the physical parts. As a result the traceability of both product and production requirements raises.

Thereby this paper provides optimization approaches in two directions. On the one hand the assembly planner is enabled to start even earlier with a first planning of the assembly work content. On the other hand the designer is assisted in the selection of connection methods.

Acknowledgement

In this paper background, objectives and some results of the research project “Prospective Determination of assembly work content in Digital Factory (Pro Mondi)” have been incorporated. This research and development project is funded by the German Federal Ministry of Education and Research (BMBF). The authors are responsible for the contents of this publication. The authors would also like to thank Torsten Gilz and Radoslav Zafirov for their contribution and research on the topic of Model Based Systems Engineering, for their input and assistance.

References

[1] Eigner, M., Ernst, J., Roubanov, D., Deuse, J., Schallow, J. and Erohin, O. (2013), “Product Assembly Information to Improve Virtual Product Development”, Smart Product Engineering, in Abramovici, M. and Stark, R. (Eds.), *Smart Product Engineering: Proceedings of the 23rd CIRP Design Conference, Bochum, Germany, March 11th - 13th, 2013*, *Lecture Notes in Production Engineering*, Springer Berlin Heidelberg; Springer, Berlin, Heidelberg, pp. 303–313.

[2] Eigner, M., Ernst, J., Roubanov, D., Sindermann, S. and Eickhof, T. (2013), "Information exchange along the Product Development Process using the example of bimetallic corrosion", Proceedings of the 19th International Conference on Engineering Design (ICED13), in Lindemann, U., Venkataraman, S., Kim, Y., Lee, S., McAloone, T. and Wartzak, S. (Eds.), *Proceedings of the 19th International Conference on Engineering Design (ICED13): Design For Harmonies, Seoul, Korea, 19-22.08.2013*, Design Society, pp. 83–92.

[3] Eigner, M., Gilz, T. and Zafirov, R. (2012), *Proposal for functional product description as part of a PLM solution in interdisciplinary product development: Proceedings of DESIGN 2012, the 12th International Design Conference*, Dubrovnik/Kroatien, pp. 1667–1676.

[4] Eigner, M., Dickopf, T., Apostolov, H. and Schäfer, P., *System Lifecycle Management: Initial Approach for a Sustainable Product Development Process Based on Methods of Model Based Systems Engineering*, to be published on PLM International Conference (PLM IC).

[5] Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.-H. (2007), *Konstruktionslehre: Grundlagen erfolgreicher Produktentwicklung ; Methoden und Anwendung, Springer-Lehrbuch,* 7. Aufl, Springer, Berlin [u.a.].

[6] *VDI 2221; Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte* (1993), Beuth, Berlin, available at: http://www.perinorm.com/search.aspx.

[7] French, M.J. (1999), *Conceptual design for engineers*, Springer, London [u.a.].

[8] Eigner, M. and Stelzer, R. (2009), *Product Lifecycle Management: Ein Leitfaden für Product Development und Life Cycle Management*, Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg.

[9] Andreasen, M.M. and Hein, L. (1987), *Integrated product development*, IFS (Publ.); Springer, Bedford, UK, Berlin, Heidelberg, New York, London, Paris, Tokyo.

[10] Ehrlenspiel, K. (2009), *Integrierte Produktentwicklung: Denkabläufe Methodeneinsatz Zusammenarbeit,* 4., aktualisierte Aufl, Hanser, München.

[11] Ponn, J. and Lindemann, U. (2011), *Konzeptentwicklung und Gestaltung technischer Produkte: Systematisch von Anforderungen zu Konzepten und Gestaltlösungen, VDI-Buch*, Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg.

[12] *VDI 2206; Entwicklungsmethodik für mechatronische Systeme; Design methodology for mechatronic systems* (2004), Beuth, Düsseldorf.

[13] Friedenthal, S., Moore, A. and Steiner, R. (2012), *A practical guide to SysML: The systems modeling language,* 2. ed, Elsevier, Amsterdam u.a.

[14] Haskins, C., Krueger, M., Walden, D. and Forsberg, K. (op. 2011), *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, INCOSE-TP-2003-002-03.2.1, Version 3.2.1, janvier 2011, INCOSE, [S.l.].

[15] Eigner, M., Gilz, T. and Zafirov, R. (2012), "Systems Engineering VPE Data Schema: PDM integration of a functional product description model in SysML", in Scheidl, R. and Jacoby, B. (Eds.), *The 13th Mechatronics Forum international conference: Proceedings; September 17 - 19, 2012, Johannes Kepler University Linz, Austria*, *Advances in mechatronics*, Trauner, Linz, pp. 651–657.

[16] Gilz, T., *PLM integrated interdisciplinary system models in the conceptual design phase based on model-based systems engineering*, to be published.