INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

INTERDEPENDENCIES DURING THE CONCEPTUAL DESIGN OF AN ANALYTICAL TELEMEDICAL DEVICE

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Keywords: interdependencies analysis, product and production system conceptual design, mechatronics, analytical telemedical device

1. Introduction

Today, mechanical engineering products are characterized by the close interaction of mechanics, electronics, control engineering and software engineering. This interaction is expressed by the term mechatronics. Not only do engineering disciplines interact strongly with each other but even manufacturing technologies interact with the conceptual design of the product and vice versa. Knowing this the product and production system have to be developed in coordination from the very beginning. Requirements of the product and its components as well as manufacturing constraints of the production system influence the product design. Today the interdependencies between product and production system are not adequately considered. In many cases the fulfillment of given requirements by the production systems becomes apparent lately. Consequently time-consuming and cost intensive iteration loops occur during the development process.
In section two, we will explain the initial situation and our field of action in context system design. In order to enable a systematic analysis of interdependencies we will introduce a method for the description of interdependencies between partial models of product and production system within the conceptual design (section 3). The present paper focuses on the interdependencies between the partial models active structure (product concept), process sequence and resources (production system). The method is validated on a telemedical device which is presented in section 4. To conclude, we will sum up the major points and give a short outlook on our future work (section 5).

2. Problem Analysis

The product development process ranges from the product idea or business idea to a successful market introduction and covers the activities related to strategic product planning, product development and production system development [Gausemeier et al. 2009b]. In our experience the product development process cannot be seen as a stringent sequence of process steps but rather an interplay of tasks that can be structured into three cycles (Figure 1).
The first cycle: Strategic Product Planning
This cycle characterizes the steps from finding the success potentials of the future to create a promising product design, what we call the principle solution. There are the three major tasks foresight, product discovering and business planning in this cycle.
The second cycle: Product Development
This cycle covers the three phases domain-spanning conceptual design, domain-specific concretization and system integration. Within the last phase the domain-specific results are integrated into one

overall solution. In this context the creation and analysis of computer models are an important part, which leads to the widely used term Virtual Product and Virtual Prototyping respectively.

The third cycle: Production System Development

The starting point of this cycle is the conceptual design of the production system. The result of this phase is the principle solution of the production system. In the further course of the third cycle the four main aspects process planning, place of work planning, production logistics and working appliance planning have to be concretized further. In this process partial models occur, which have to be integrated to a coherent system of partial models.

The product and the production system have to be developed in a close interplay. This is in particular necessary for complex products, whose concept is affected by the considered manufacturing technology. Because of this, the product development and the production system development are arranged in parallel. The horizontal arrows in the model of three cycles emphasize, that the conceptual design of product and production system has to be dealt in a close interplay. In this context, the principle solution of the product constitutes the starting point for the production system´s conceptual design. The partial models of the product concept [Gausemeier et al. 2009a] and production system concept [Gausemeier et al. 2009b] are now discussed in detail.

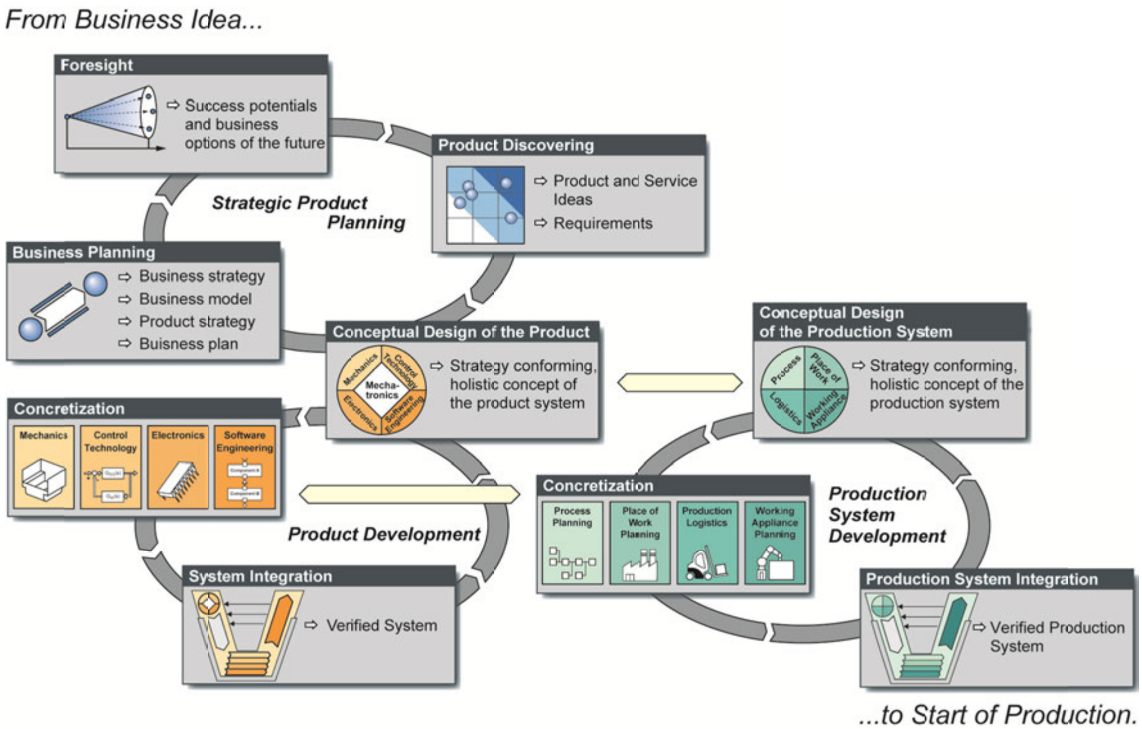

Figure 1. 3-cycle-model of product design according to Gausemeier

Application Scenarios: Application scenarios form first concretizations of the system. They concretize the behavior of the system in a special state and a special situation and furthermore, initiate a certain state transition for types of events. Application scenarios characterize a problem, which needs to be solved in special cases, and also roughly describe the possible solution.

Environment: This model describes the environment of the system that has to be developed and its embedding into the environment. Relevant spheres of influence (such as weather, mechanical load, superior systems) and influences (such as thermal radiation, wind energy, information) will be identified. Disturbing influences on the purpose of the system purpose will be marked as disturbance variables. Furthermore, the interplays between the influences will be examined. We consider a situation to be one consistent amount of collectively occurring influences, in which the system has to work properly. We mark influences that cause a state transition of the system as events. Catalogues, that imply spheres of influences and influences, support the creation of environment models.

Requirements: This aspect considers the computer-internal representation of the requirements. The list of requirements sets up its basis. It presents an organized collection of requirements that need to be fulfilled during the product development (such as overall size, performance data). We distinguish between functional and non-functional requirements. Functional requirements describe the desired functionality of the system. Non-functional requirements describe properties of the system itself as well as of its behavior. Every requirement is textually described and, if possible, concretized by attributes and their characteristics. There are checklists that assist the setting up of requirements, see for example [Roth 2000], [Pahl et al. 2007].

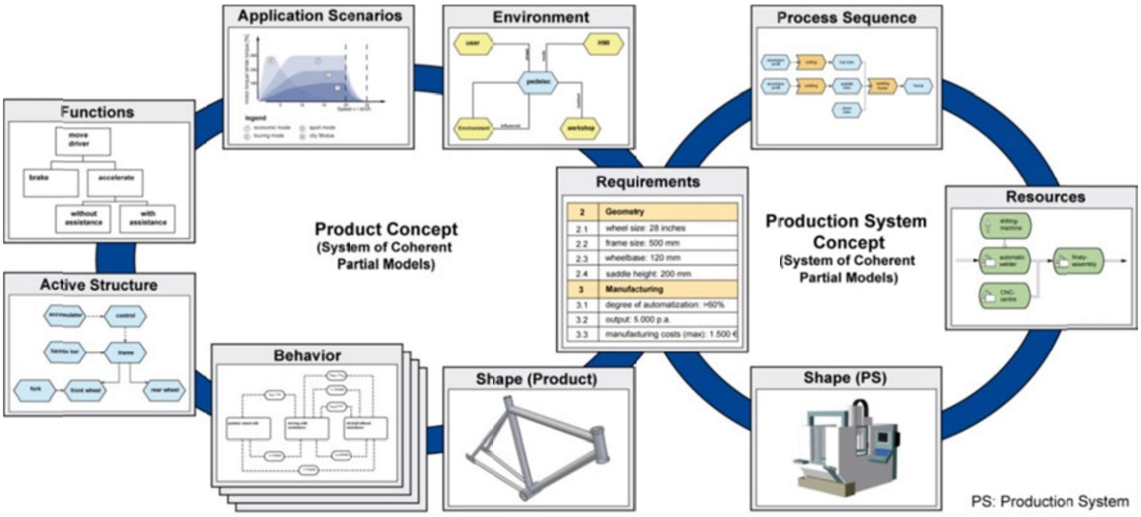

Figure 2. Partial models for the domain-spanning description of the product concept and production system

Functions: This aspect concerns the hierarchical subdivision of the functionality. A function is the general and required coherence between input and output parameters, aimed at fulfilling a task. The set up of function hierarchies is based on a catalogue with functions. [Langlotz 2000]. Functions are realized by solution patterns and their concretizations. A subdivision into sub functions will take place until useful solution patterns have been found for the functions.

Active Structure: The active structure describes the systemelements, their attributes as well as the relation of the systemelements. The active structure consists of systemelements, such as drive and brake modules, air gap adjustment, operating point control, tracking modules, spring- and tilt modules, energy management and their relations. Furthermore, incoming parameters are described, such as comfort, costs and time, which are external objectives of the user.

Behavior: Two partial models are used to specify the behavior of the system. These are the partial models behavior – states and behavior – activities. The partial model behavior – states defines the states of the system and the state transitions. The state transitions describe the reactive behavior of the system towards incoming events. The partial model behavior – activities describes the logical sequence of activities in the system. Especially, parallel executed activities and their synchronization can be described this way.

Shape (Product): This aspect needs to be modeled because first definitions of the shape of the system have to be carried out already in the phase of the conceptual design. This especially concerns working surfaces, working places, surfaces and frames. The computer-aided modeling takes place by using 3D CAD systems.

The starting point for the development of the production system is the principle solution and not the ultimately defined product because the development of the production system must be executed concurrently with the development of the product, as mentioned before. The conceptual design of the production system begins as soon as relevant information for production is available. The partial models for the production system [Gausemeier et al. 2010] are described in the following:

Process sequence: This partial model describes the manufacturing operations (activities) and their sequence as a chain of processes. We refer to the processes as manufacturing processes and assembly processes. Each process is characterized by a manufacturing function and additional attributes (requirements, process parameter). According to product functions, manufacturing functions are described by a substantive and a verb (e.g. machining the housing, assemble wheels). During the conceptual design the manufacturing functions are concretized into manufacturing processes and manufacturing technologies. Manufacturing processes are considered predominantly manufacturing processes according to the standard DIN 8580 [DIN8580 1974]. Each process has at least one input-object and at least one output-object. The input and output objects are referred to as material elements. That includes all raw materials, auxiliary materials, components from suppliers and trade goods, as well as raw, unfinished and finished goods [Gienke and Kaempf 2006]. For instance processes are detailed by further information, requirements and shape. Manufacturing processes carry out a transformation of components and assemblies with regard to form and material properties.
Resources: This partial model describes the resources that execute the processes within the process sequence partial model. We refer to resources as all equipment, tools and personnel that are required for the execution of processes [DIN69902 1987]. The resources are allocated to the processes of the process sequence. It is possible that one resource realizes more than one process. The resources are connected by arrows indicating the material flow. It is derived from the process sequence. Resources are concretized by requirements, parameters and shape.
Shape (Production System): Along the lines of conceptional design of the product, first definitions of the shape are made during the conceptional design of the production system. We refer to the shape as workspace, the required floor space of machines or the active areas of handling appliances. The information is stored as written specifications, sketches or CAD data. Information regarding the shape of the production system is necessary for the concretisation within the development process especially for the place of work planning and the working appliance planning.
Many interdependencies exist between the partial models of the product as well as the partial models of the production system. As already mentioned, the development of the product and production system must me done concurrently. There are also many interdependencies between both product partial models and production system partial models. For instance existing interdependencies of the partial models of the product and production system are shown in Figure 3. The systemelements of the active structure are related to the process sequences. These processes are related to resources.

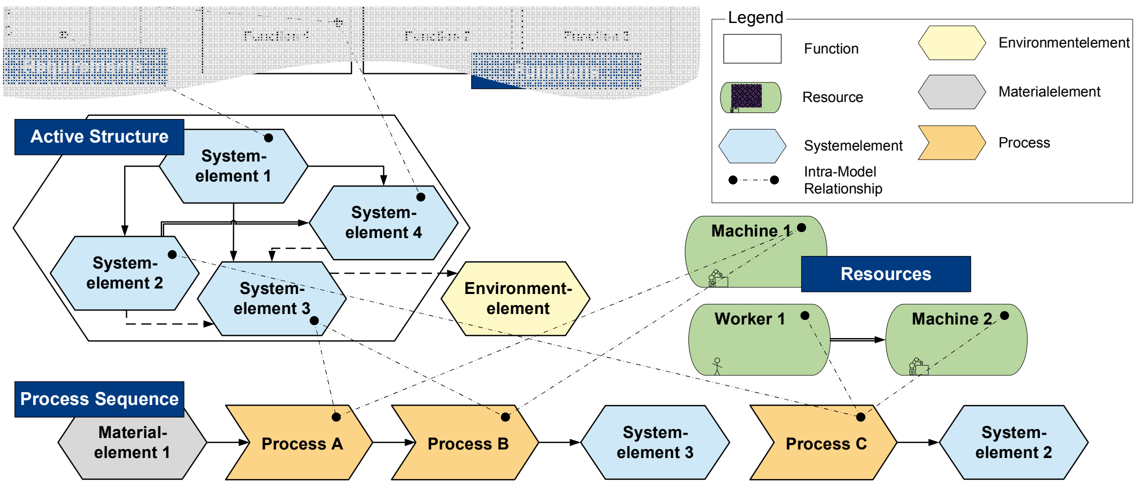

Figure 3. Schematic overview of interdependencies between partial models of product and production system (excerpt)

Interdependencies are versatile but are often not easy to recognize. A direct link between the shown partial models is missing. Hence requirements, process parameters and resource parameters are not connected directly.
Today there are some approaches which deal with this conditions. Many tools (e.g. Doors or Catia V6) provide the possibility to connect different model elements like requirements and systemelements.

With PrEMISE developers are able to connect parameters with system components [Schumann and Berres 2011]. Another Tool in this context is IsYFMU which visualizes connections between different models [Stark et al. 2010], [Stark and Figge 2011]. Other matrix-based approaches are e.g. Domain Mapping Matrices (DMM) or Multiple Domain Matrices (MDM) which connect different aspects with each other [Lindemann et al. 2009]. Those connections can be visualized by LOOMEO [Mirson et al. 2011]. Eigner et al. propagate an SysML based RFLP (Requirments, Functions, Logical, Physical) with a PDM-Backbone. Those approaches only concentrate on the connection and visualization [Eigner et al. 2012]. The elements often have to be connected manually. A consideration of interdependencies between different partial models and change-impact of involved disciplines is not considered sufficient. Especially complex products with a large number of systemelements lead to a challenging consideration of inderdependencies. Therefore we developed a method for the description of interdependencies between the mentioned partial models, which we are going to present in the next chapter.

3. Method for the description of interdependencies between partial models of product and production system within the conceptual design

The following presents the method for the description of interdependencies between the partial models active structure, resources and process sequences. Therefore we use the given information in each partial model to divert the matrices shown in Figure 4.

The upper left matrix shows the interrelations between the systemelements of the product. The flows are differentiated into itemflow (a), energyflow (b) and informationflow (c). Furthermore the flow direction is also differentiated: incoming flow, outgoing flow, bidirectional flow and disturbing flow. The position of the character in the rectangle shows the direction of the flow. For instance systemelement 1 has an outgoing energyflow to systemelement 3. The reading direction is from row to column. The sum shows how many interdependencies exist for the systemelement within the active structure. The higher the sum, the more complex the interdependencies between row and column are.

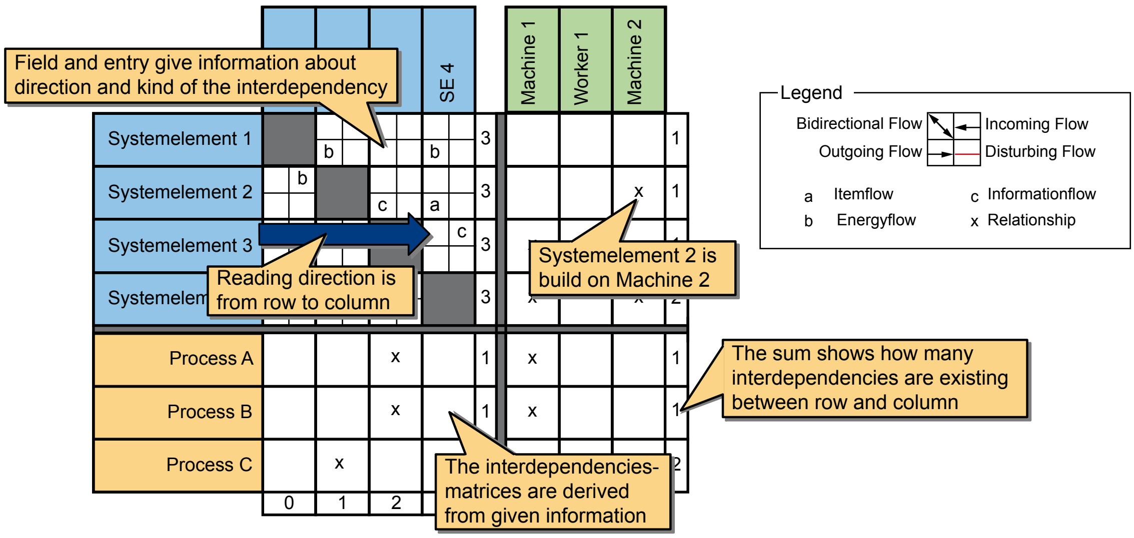

Figure 4. Description of interdependencies between partial models active structure, process sequence and resources

The lower left matrix shows the relationship between each process (row) and each systemelement (column). An “x” in the rectangle symbolises a relationship. Again, the sum shows how many interdependencies exists between each process and each systemelement. For example: process C is related to systemelement 2. The lower right matrix shows the relationship between the processes and resources. Each “x” in the rectangle shows which resource is needed by a specific process. Again, the sum shows how many interdependencies exist between each process and each resource. For instance, process C is performed by worker 1 and machine 2. The upper right matrix is also derived by the given information. The relationship between systemelement and resource can not be easily considered. The relationship is derived within the information of the three existing matrices respectively of partial models. For products and production systems with a small number of systemelements, process sequences and resources the analysis of interdependencies might be easy. But with an increasing complexity of the product and the production systems the investigation of interdependencies becomes more and more difficult. A systematic description of interdependencies between partial models of product and production systemenables an analysis of interdependencies of complex products with a large number of systemelements.

4. Demonstrator – analytical telemedical device

The method mentioned in section 3 was used within the conceptual design of an analytical telemedical device. The telemedical device measures various vital parameters and can send the results to a database system. During the in- or outpatient therapy it can be used for monitoring the therapy progress continuously. Doctors and nursing staff can use the database system to control the healing process location-independently. An analysis function helps health personnel customize the therapy activities the patient requires. The telemedical device integrates sensors for measuring blood pressure, pulse, oxygen saturation, skin conductance and glucose as well as a smartphone for user interaction, communication and energy supply. Because of the integration of all components in one body, the device is easy to handle and can be integrated into everyday life. Figure 5 shows 3D-models of all components and the finished product.

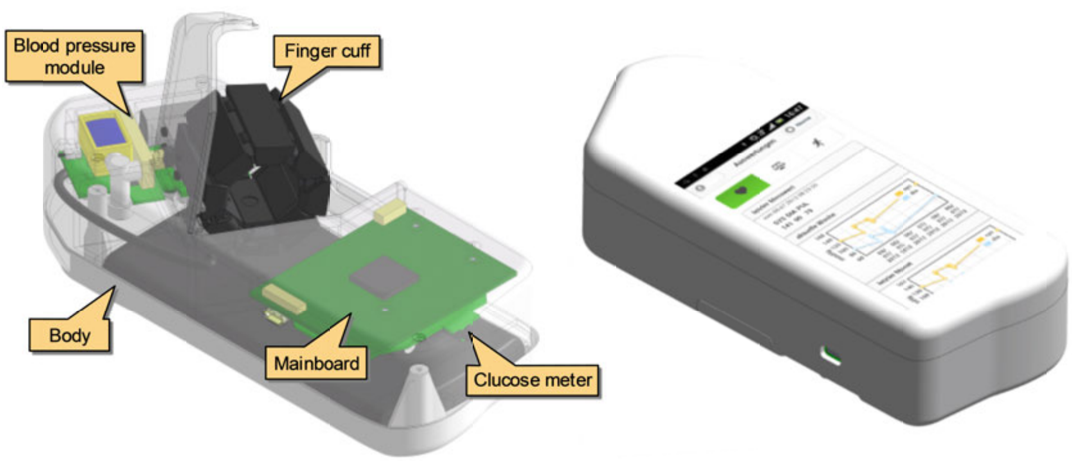

Figure 5. 3D-models of the analytical telemedical device

Manifold applications of the analytical telemedical device lead to various requirements. Especially the body has to fulfill diverse requirements in order for the device to be approved to be used in hospitals and nursing facilities. In order to ensure the fulfillment of requirements it is important to analyse the interdependencies within the product, within the production system and between product and production system. The analysis of interedependencies is based on the partial models active structure, process sequences and resources. Figure 6 shows the required partial models of the telemedical device in excerpts.

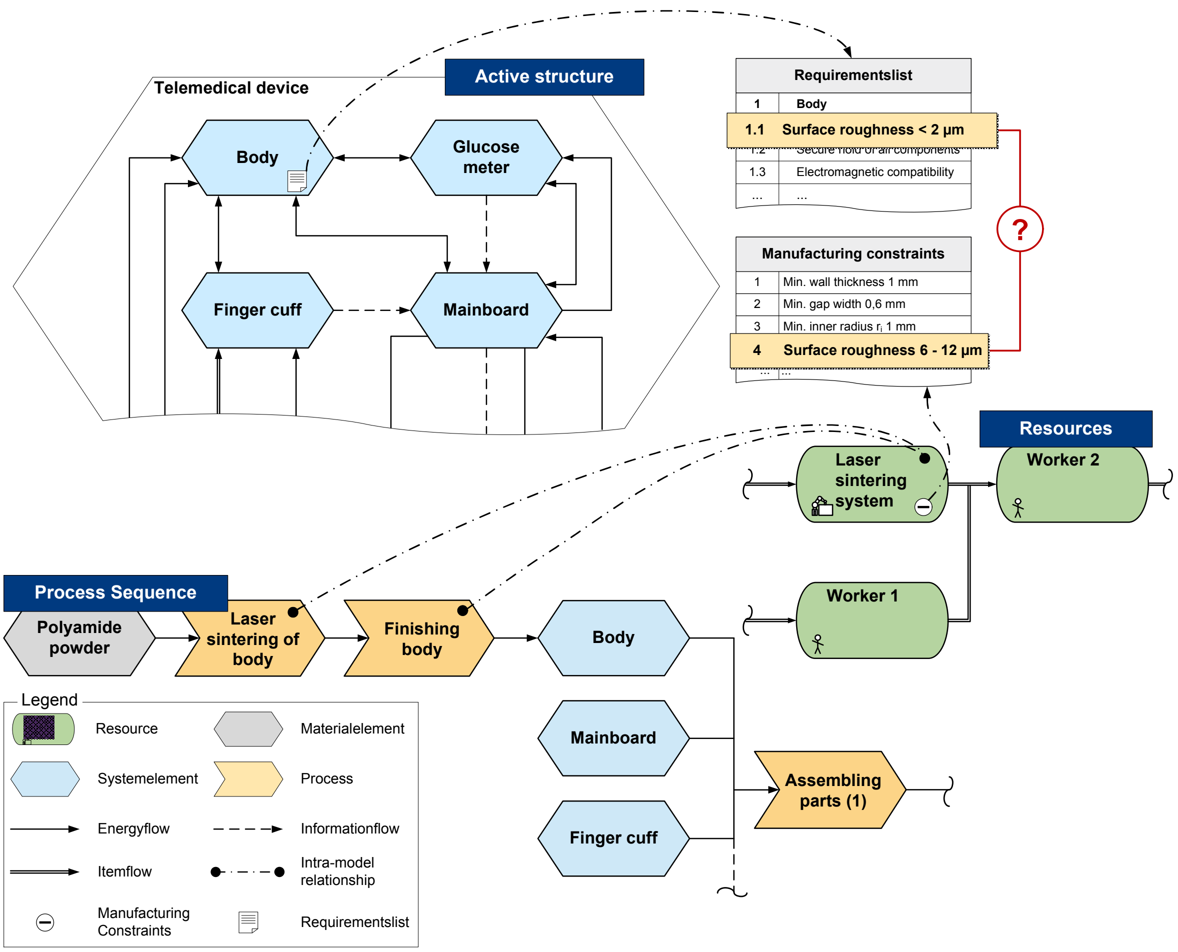

Figure 6. Analysis of interdependencies between systemelement "body", its process sequence and resources (excerpt)

The active structure illustrates that the body is connected with the glucose meter, the mainboard, the finger cuff and the smartphone. Thus the body has connections to all components integrated in the telemedical device. The body will be produced by using polyamide powder and a laser sintering system. This is shown in the partial models process sequence and resources. The laser sintering process is a highly automated additive manufacturing process. Thus only two process steps are needed to produce the body.

On the one hand laser sintering offers a high level of flexibility regarding the component design but on the other hand diverse manufacturing constraints have to be considered. For example polyamide components produced by laser sintering have a high surface roughness. This process characterics are contradictory to the requirements of the body, which must have a very low roughness for usage in medical applications. Consequently modifications of the product, the process sequence or the resources have to take place to fulfill the requirements. Changes can lead to time and cost intensive efforts. In order to avoid intensive change efforts in the late phase of the product development process an analysis of interedepencies during the conceptual design allows an investigation of alternative changes.

Figure 7 shows an excerpt of the matrices of the telemedical device. During the conceptual design we recognized, that the requirement "surface roughness <2 µm" could not be fulfilled by the desired production technology with the given laser sintering system. The best possible surface roughness is between 6 to 12 µm. The gap between surface requirement and the best possible surface roughness arose because the restrictions of the technolgy laser sintering was not known in detail.We analysed the interdependencies by using the method for the description of interdependencies between partial models of product and production system within the conceptual design.

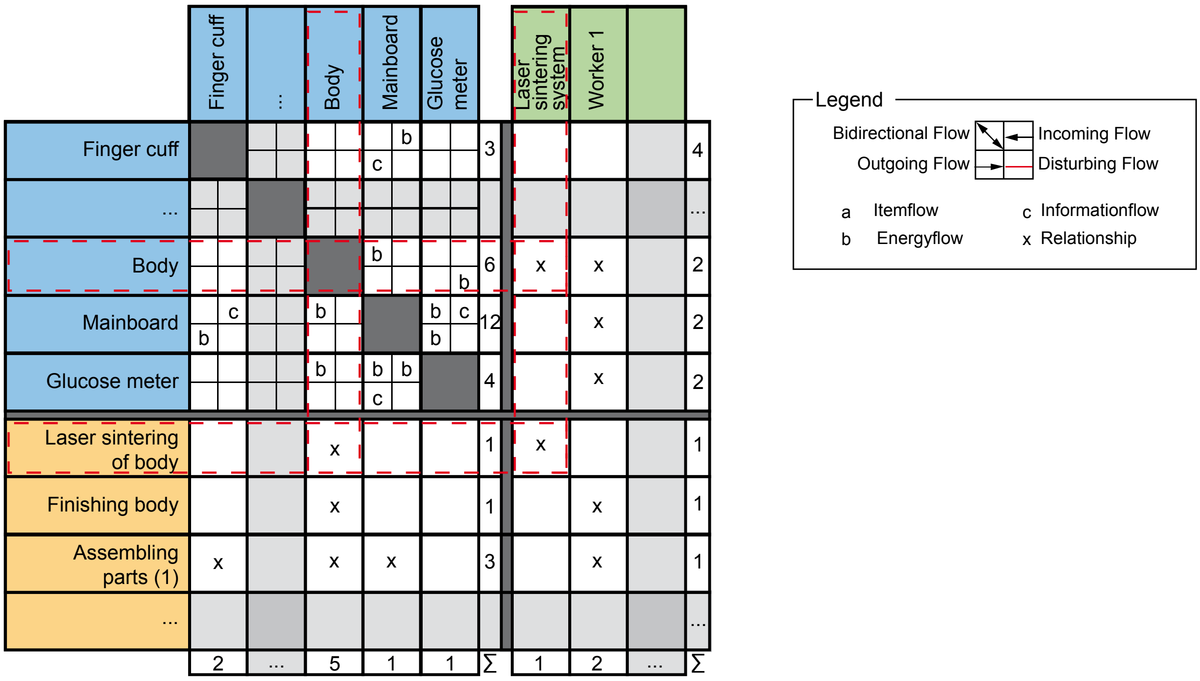

Figure 7. Interdependencies-matrices of systemelements, process sequence and resources of the analytical telemedical device (excerpt)

Thus, the matrices can help to identify possible leverages to overcome the gap between requested surface quality and provided surface quality. With the help of the matrices possible change efforts can be considered. As one can see a possible change is the replacement of the used resource. This acquires that the process step has to be replaced, too. The laser sintering system is only used to produce the body and is furthermore the only resource which is used in the laser sintering process ("laser sintering body"). Another possible technology which fulfills the requirement of surface roughness is the technology "fused deposition modelling" (FDM). FDM is conducted by another process and resource. As mentioned before the replacement of resource and process is easy because there are no other interdependencies within the production process. But FDM comes with some other constraints. One constraint is the need of a supporting structure if undercuts are used in the body design, as done here. This means the body has to be changed. The sum in the upper left matrix of the body is six. That means, that the body has some interrelations within the product. The change of the body possibly causes several other changes within the product concept. Another possibility is to add another process step to generate a better surface quality. Therefore a worker is needed. As one can see a worker is already needed to finish the body. Another downstream process can easily solve the problem. No further changes are needed. Figure 8 shows an excerpt of the new process sequence of the analytical telemedical device.

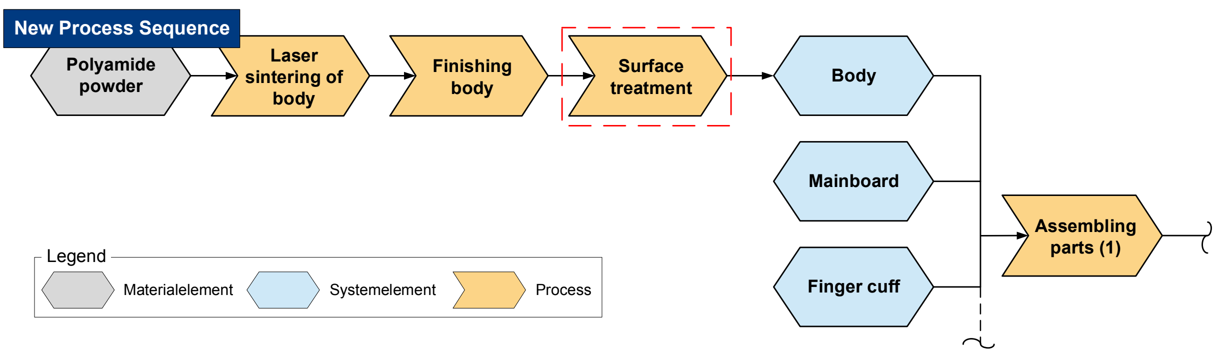

Figure 8. New process sequence including the process step "Surface treatment" (excerpt)

5. Conclusion and Outlook

Already at the conceptual design the relationships between product and production system have to be taken into account. In order to analyse interdependencies systematically, the proposed method describes the interdependencies between partial models of product and production system within the conceptual design. Based on the description of interdependencies, various investigations can be executed. A systematic investigation of interdependencies is important to identify crtical components of product and production system and to verify the fulfillment of product requirements by the production system. Furthermore it is useful to determine the influence of the product on the production system and vice versa. The investigation of intederdependencies points out deficiencies of the product concept and its production system and avoids intensive change efforts in the late phases of the development process. If changes are necessary, efforts of alternative changes can be estimated to identify the optimal solution.

Acknowledgement

This contribution was developed in the course of the KOMPASS (Cognitive Medical Personal Assistance System) funded by the Heinz Nixdorf Foundation.

References

DIN 69902, "DIN 69902 – Projektwirtschaft Einsatzmittel Begriffe", DIN Deutsches Institut für Normung e.V., Beuth Verlag, Berlin, 1987.

DIN 8580, "DIN 8580 – Fertigungsverfahren, Einteilung", DIN Deutsches Institut für Normung e.V., Beuth Verlag, Berlin, 1974.

Eigner, M., Gilz, T., Zafirov, R., "Proposal for functional product description a part of a PLM solution in interdisciplinary product development", In: Proceedings of the International DESIGN Conference, Dubrovnik, 2012.

Gausemeier, J., Brandis, R., Reyes-Perez, M., "A Specification technique for the integrative conceptual design of mechatronic products and production systems", Proceedings of the 11th International Design Conference – Desgin 2010, D. Marjanovic (Ed.), Dubrovnik, Croatia, 2010, pp. 711-722.

Gausemeier, J., Frank, U., Donoth, J., Kahl, S., "Specification technique for the description of self-optimizing mechatronic systems", Research in Engineering Design, Vol. 20, No. 4, 2009, pp. 201-223.

Gausemeier, J., Plass, C., Wenzelmann, C., "Zukunftsorientierte Unternehmensgestaltung – Strategien, Geschäftsprozesse und IT-Systeme für die Produktion von morgen", Carl Hanser Verlag, Munich, 2009.

Gienke, H., Kaempf, R., "Praxishandbuch Produktion – Innovatives Produktionsmanagement: Organisation, Konzepte, Controlling", Carl Hanser Verlag, Munich, 2006.

Langlotz, G., "Ein Beitrag zur Funktionsstrukturentwicklung innovativer Produkte", Dissertation, Institut für Rechenranwendung in Planung und Konstruktion, Universität Karlsruhe, Shaker-Verlag, Aachen, Band 2, 2000.

Lindemann, U., Maurer, M.; Braun, T., "Structural Complexity Management – An Approach for the Field of Product Design", Springer-Verlag, Berlin, 2009.

Mirson, A., Skrypnyuk, O., Elezi, F., Lindemann, U., "MDM-Based Software Modularization by Analyzing Inter-Project Dependencies", In: Proceedings of the 13th International DSM Conference, DSM'11. September 13th/14th 2011, Cambridge, 2011.

Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H., "Engineering Design – A Systematic Approach", 3rd English edition, Springer Verlag, London, 2007.

Roth, K.-H., "Konstruieren mit Konstruktionskatalogen, Band 1, Konstruktionslehre", Springer Verlag, Berlin, 2000.

Schumann, H., Berres, A., "Modellbasierter Systementwurf mit dem PrEMISE-Modell", In: Tag des Systems Engineerings 2011 (TdSE). 10th-11th November 2011, Hamburgm Carl Hanser Verlag, München, 2011.

Stark, R., Beier, G., Figge, A., Wöhler, T., "Cross-Domain Dependency Modelling – How to achieve consistent System Models with Tool Support", In: Proceedings EuSEC 2010 – European Systems Engineering Conference. May 23rd-26th 2010, Stockholm, 2010.

Stark, R., Figge, A., "Eco Tracing – A Systems Engineering Method for Efficient Tracelink Modeling", In: Proceedings of the International Conference on Engineering Design ICED2011, August 15th-18th 2011, Copenhangen, 2011.

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