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AN APPROACH TO HANDLE UNCERTAINTY DURING THE PROCESS OF PRODUCT MODELLING

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Abstract

Product models are the results of product modelling and are used for decision making during the development process. They are based on assumptions by the designer, which are made under a lack of information, so the designer has to make assumptions under uncertainty. This paper systematizes the process of product modelling to assist understanding of what the designer do during that process. With the help of that, a methodical support is developed which the designer can use to define a viewing frame for the product model. It is based on the function-process relationship and the question, in which way the product behaves if identified influencing factors occur.

Keywords: Uncertainty, Product modelling / models, Design methods

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1 INTRODUCTION

The main task of designers is to create new technical products to solve problems by using their engineering knowledge (Pahl and Beitz, 2007). By designing the product, the designer has to fulfil various phases. VDI 2221 for example distinguishes between the phases *Clarifying the task*, *Conceptual design*, *Embodiment design* and *Detail design* (VDI 2221, 1993). The phases describe a product development process as a systematic concretisation of the product.

During these phases, the designer needs product models. They represent the product at a defined level of abstraction, contain only information relevant to a certain task and are the results of the process of product modelling (VDI 2221, 1993). Product models are used in decision support for certain tasks or problems during the product development process, for example, to define or verify product properties.

During the product development process, information about the product being developed is partly unknown or vague, creating a gap between available levels of information and required levels of information for a certain task.

This may lead to uncertainty when relevant information is neglected or insufficient; the product model can be incomplete or unsuitable for the given task. In this approach uncertainty is a situation that results from completely or partially missing information, understanding or knowledge (DIN 31000, 2009) and occurs during the process of product modelling (Eifler et al., 2011). A product model with a high level of uncertainty affects the definition or verification of product properties, whereby the product behaviour is influenced, so it is possible that the product does not behave as desired. There's a time gap between the occurrence and the effect of uncertainty, so uncertainty appears in lifecycle processes of the product. In order to avoid a gap between desired and realized product behaviour, the designer has to be supported during the process of product modelling. Therefore, it is necessary to understand what the designer does during that process.

2 THE PROCESS OF PRODUCT MODELLING

Before the designer begins with the modelling process, he interprets the original product (Figure 1).

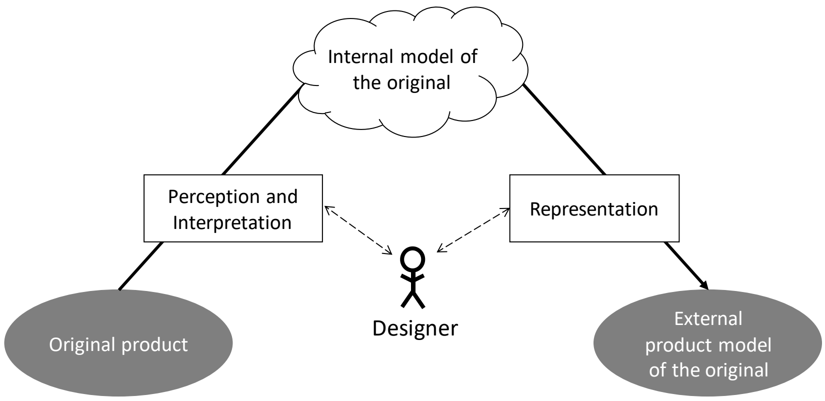


Figure 1. Representation of a product model (Kohn, 2014 and Falkenberg et al., 1998)

The result of the first step is an internal model that is highly dependent on the knowledge and experience of the designer. That part is very difficult to support because of the pronounced heterogeneity of the designers' skills. After that, the designer externalises the internal model to an external one by representing his interpretation and perception of the original product. This step is an observable process, so it can be described in a formal way and is called in the following sections as the *process of product modelling* (Würtenberger, 2015 and Würtenberger, 2016).

Based on previously published papers, four sub-processes are identified which describe a continuous individualization of the product model (Figure 2).

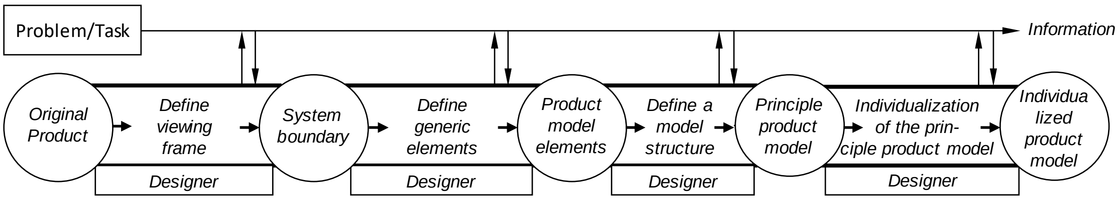


Figure 2. Process of product modelling

The initialization of the product modelling process is a task for which the designer needs a product model to solve it. Based on that, he has to think about which elements from the product such as from the environment have to be investigated, whereby he defines a viewing frame. The product itself is seen as a technical system, so it stays in interaction with the environment (Hubka, 1984).
After that, the system boundary is defined and the designer has to choose generic elements during the second sub-process to translate the chosen relevant elements into a product model (Figure 3).

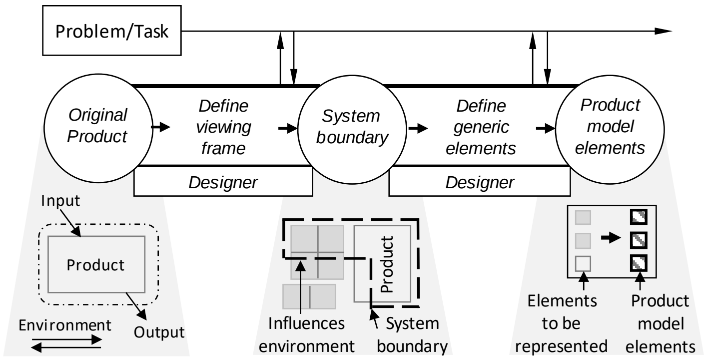


Figure 3. Sub-processes define viewing frame and define generic elements

Keeping the internal model in mind, the designer selects a modelling strategy which is suitable for the task and can represent all relevant elements. The strategies can be classified according to different subject areas out of the field of mechanical and process engineering, for example mechanics of material, structural dynamics, or thermodynamics. The next sub-process focuses on the definition of the model's structure. The designer has to decide in which way he wants to represent the relevant elements, so he allocates elements out of the system to the generic elements and combines them to a model structure until the principle product model is finished (Figure 4).

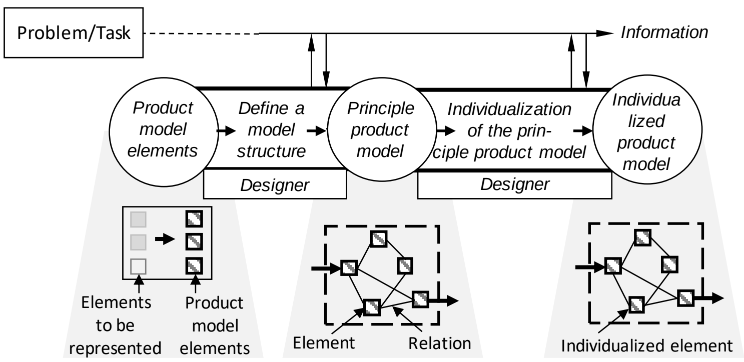


Figure 4. Sub-processes define viewing frame and generic elements

At least, the principle product model has to be individualized by defining parameters, for example geometric dimensions or material properties. After that, the individualized product model is finished and the designer can use it to solve the problem or task.
The first sub-process has the highest sensitivity to the level of uncertainty in a product model, because all further sub-processes depend on the definition of the system boundary. If an important aspect is missed here, it isn't considered anymore during the whole process of product modelling.
This statement is explained with the help of the General Motors Ignition switch recall ten years ago. The problem here was that the ignition switch unintentionally switched from the Engine-On position to the

Off-position while the car was driven due to a wrongly dimensioned spring (Figure 5). One reason for that problem was a high tolerance of the spring force of the plunger, which holds die ignition key in the ON position.

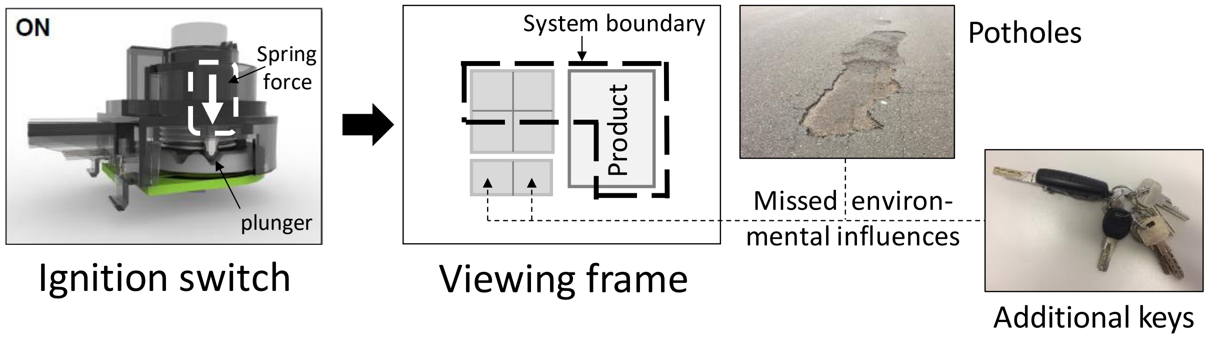


Figure 5. General motors ignition switch recall (Eifler et al. 2014)

Furthermore, two decisive elements out of the environment were not investigated in combination during product modelling. It was missed that there could be additional keys on the ignition key. In combination with potholes, an additional torsional torque arises which leads to the shutdown. Both elements can be allocated to the first sub-process of product modelling by defining the viewing frame.
It can be noted that the designer needs a methodical support defining the viewing frame for a product model during the first sub-process of product modelling in order to avoid such a disaster.

3 METHODICAL SUPPORT FOR THE DESIGNER

As mentioned above, the product for which a product model has to be created is seen as a technical system, so the product stays in interaction with the environment. The environment itself can be described in lifecycle processes. By defining a viewing frame for a product model, the designer has to choose elements from the product such as elements from relevant lifecycle processes regarding the purpose of the product model, whereby both types of elements stay in interaction.
Based on that and the understanding of uncertainty, that it occurs during product modelling and their effect becomes clear during lifecycle processes, a systematic methodical support for the designer during the first sub-process of product modelling can be defined. The idea is to guide him by choosing relevant elements, starting with the lifecycle processes and go over to link them with the product by defining cause-effect relationships using existing methods or methodologies.
Keeping that in mind, a division of the first sub-process into the working steps *Identification*, *Detailing*, *Determination of effects* and *Evaluation and Prioritization* is useful (Figure 6). In the following sections the working steps are explained and it is described in which way the designer can be supported.

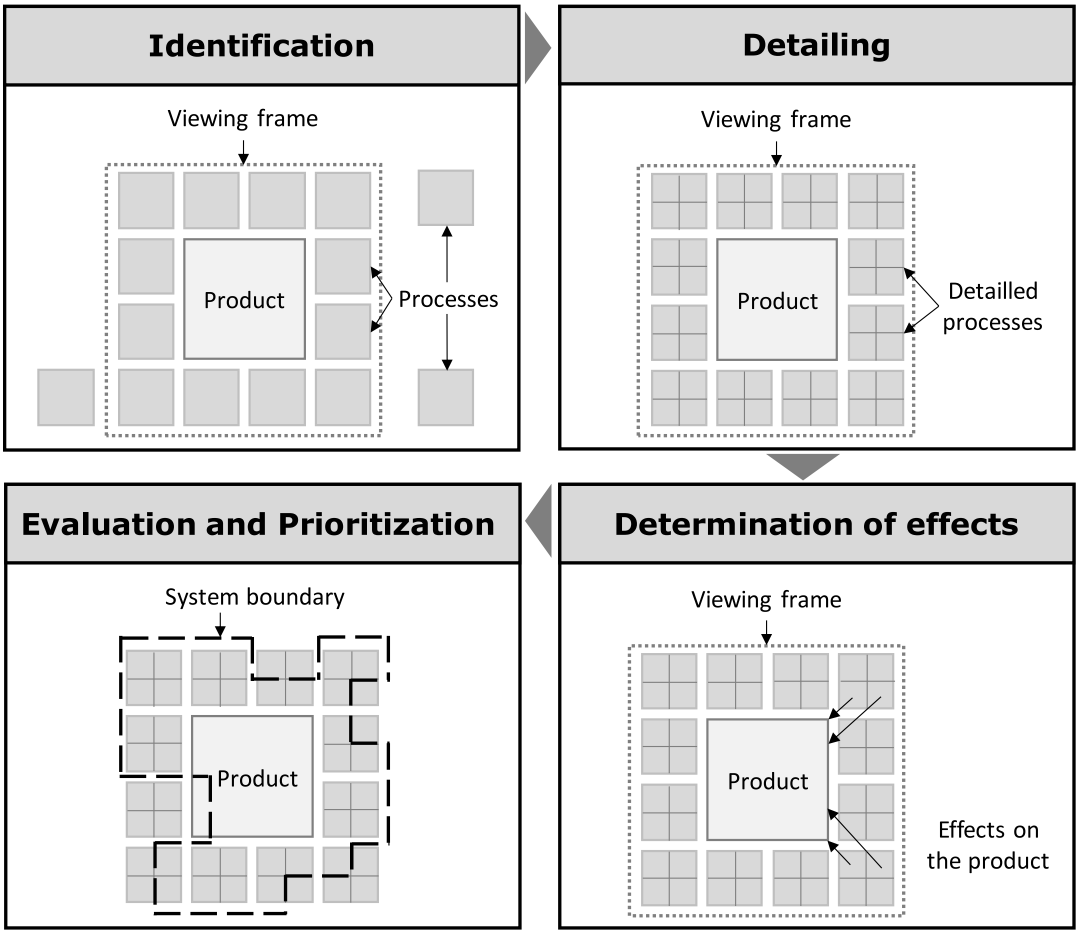


Figure 6. Working steps to define a system boundary

3.1 Identification

During the first working step the designer defines processes out of the lifecycle which are relevant for the purpose of the product model, whereby he defines a viewing frame by selecting them. It is the starting point of the externalisation from the intern to the extern product model. In order to minimize uncertainty, the selection has to be as complete as possible. To support the designer here, the use of lifecycle checklists or the analysis of the product environment are suitable.

3.1.1 Lifecycle checklists

Lifecycle checklists are mainly used during the product development process to identify requirements to the product. They contain key questions or keywords which can be relevant for development tasks and they are classified using the product lifecycle. Birkhofer for example distinguishes between the categories product development itself, production planning, assembly, transport and storage, marketing and distribution, usage, maintenance and repair such as recycling and disposal (Birkhofer et al., 2012). The designer can use them to check the defined viewing frame and revise the process selection.

3.1.2 Analysis of the product environment

The method analysis of the product environment analyses the interaction of the product as a technical system with neighbour systems. In literature exists different types of it, whereby the considered neighbour systems changes. Roth for example distinguishes between six systems (Roth, 2001):

- A passive working system, on which an effect takes place,
- an active working system, which has an effect on the product,
- a command system, which controls the product,
- a working place,
- a transport system such as
- a maintenance system.

For each of the systems exist structured key questions, for example who works with, when and where it takes place or what happened (Roth, 2001). The answers are documented in a special form in order to structure it. With the help of that, the designer can think about missed aspects and can adapt his viewing frame.

3.2 Detailing

During the next working step the identified relevant lifecycle processes are detailed in order to get to know, which factors out of the environment influence the processes. For this purpose, it is useful to represent the relevant processes with the help of the SFB 805 process model (Figure 7).

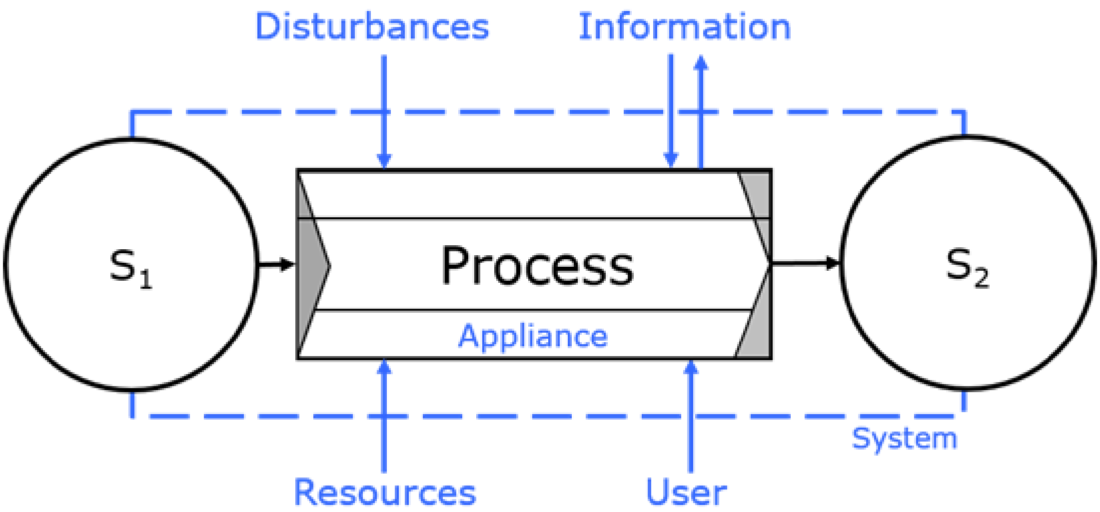


Figure 7. SFB 805 process model (Eifler et al., 2011)

The model was developed within the Collaborative Research Centre SFB 805 to analyse uncertainty in lifecycle processes. It describes the transformation of state S1 to state S2 within a system boundary. To fulfil the transformation, an appliance that provides the working factor is necessary. For example, if a bending process is considered during the production of a product, a bending machine is the appliance and provides a bending force. The state S1 then can be described by the geometrical dimensions of a sheet metal length and width and the state S2 by the dimensions length, width and bending angle.
The process is affected by the influencing factors disturbances, information, resources and user. Disturbances result from downstream and upstream processes that are outside the system boundary as well as from environmental influences like air humidity or temperature. An example of information could be fabrication information, guidelines or instructions. Resources describe what the appliance requires to fulfil the process, for example, operation and auxiliary materials like energy or coolant. Examples of user influences are dexterity, qualification and experience.
To define influencing factors, various methods can be used, for example disturbance checklists or the method Failure Mode and Effect Analysis.

3.2.1 Disturbance checklists

Disturbance checklists give the designer a large number of possible influencing factors which he can allocate to the SFB 805 process model. In literature exists different types of checklists. A useful version for that working step is a standardised disturbance checklist by Mathias (Mathias, 2016). Figure 8 gives some examples of such a checklist.

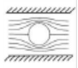
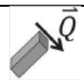
No.	Disturbance	Pictogram	No.	Disturbance	Pictogram
1	Alpha radiation		43	Structure-borne noise	
2	Newton gravity		44	Laminar flow	
3	Increasing of the angular velocity		45	Normal force	
4	Electrical overload		46	Shear force	

Figure 8. Extract from the disturbance checklist (Mathias, 2016)

3.2.2 Failure Mode and Effect Analysis (FMEA)

The FMEA is a systematic procedure to analyse a system in order to identify failure modes and their causes and effects on the rest of the system (DIN EN 60812, 2006). It can be applied during the whole product development process. The FMEA contains 5 steps that have to be executed. First of all, with the help of a failure mode analysis every potential failure of a product is identified. After that, causes and effects on the planned usage process are assigned for each failure. Every combination of failure, cause and effect is evaluated with the help of a Risk Priority Number (RPN). The RPN can be calculated using the probability, severity and detection of a failure. Finally mitigation strategies are identified in order to avoid or lower severity and detection of a failure.
The results of the FMEA can the designer use to think about further influences on the relevant processes. Especially the cause of failures are of relevance for him, because he can link them to additional potential influencing factors and fill them into the process model.

3.3 Determination of effects

After detailing the relevant processes, the designer determines effects of the identified influencing factors on the product. Therefore, the investigated product has to be prepared. As mentioned above, the product is seen as a technical system which fulfils a certain purpose. In order to realize it, the product has a certain function with inputs and outputs. The function can be described on different abstract levels depending on the progress of the product development process. Figure 9 gives a short example how function of a product can be concretised during the development process using a heat exchanger.

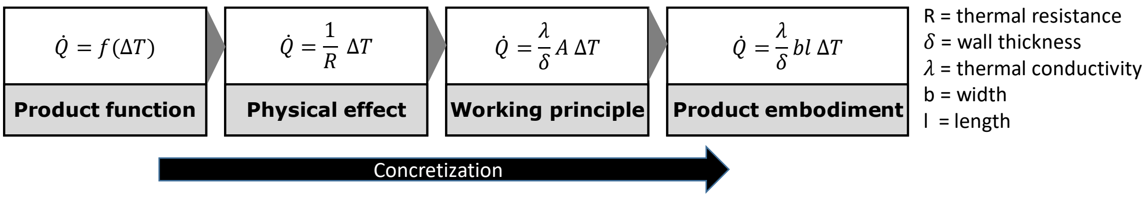


Figure 9. Concretization of the function using a heat exchanger (Gramlich, 2013)

The designer has to identify all functions of the investigated product and fill them into the first row of a matrix (Figure 10). To support him here, standardised descriptions of functions can be used for example by Pahl and Beitz 2007, Krumhauer 1974 or Koller 1994. Furthermore, the designer fills in all identified influencing factors into the first column of the matrix. After that, potential effects from the influencing factors to the product functions are analysed. The reason for this working step is, that the fulfilment of a function is always affected by the lifecycle processes, whereby the product behaviour is recognisable. The designer translate the identified influencing factors into physical effects and fill them into the matrix (Figure 10). Checklists of physical effects supports the designer by the identification and allocation to the influencing factors.

Based on that, the function-process relationships are analysed by thinking about in which way the functions are affected by the physical effects. Identified dependencies are filled in into the matrix in a verbal way. For example the influencing factor temperature leads to the physical effect expansion, which may causes constraint forces in an actuator and reduces its efficiency (Figure 10).

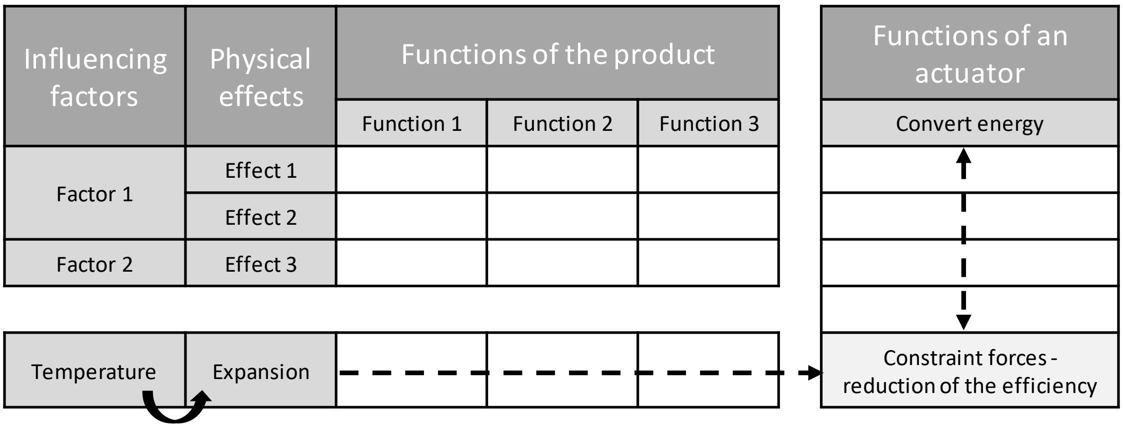


Figure 10. Matrix to determinate effects

3.3.1 *Checklists of physical effects*

Checklists of physical effects gives the designer an overview of physical phenomenon which occur in nature. Depending on the author of those checklists, for example Koller 1994 or Ehrlenspiel 2009, different possibilities exist to categorise them. Figure 11 gives some examples.

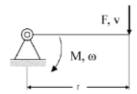
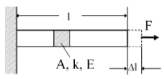
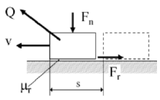
Description	Schematic sketch	Model equation
Leverage effect		$M = F \cdot r$
Elastical expansion		$F = k \cdot \Delta l$
Coulomb friction		$F_r = \mu_r \cdot F_n$

Figure 11. Checklist of physical effects (Koller 1994 and Ehrlenspiel 2009)

3.4 Evaluation and prioritization

After the determination of effects is finished, all identified dependencies are evaluated and prioritised. The designer defines function-process relationships which he wants to investigate in more detail during the following sub-processes of product modelling. To support the evaluation, the designer can use risk management, whereby he has to rate the importance of the relationship such as its effect. The results are represent in a portfolio and support the prioritization. Finally, the designer has to choose relevant relationships, whereby the system boundary for the product model is set.

4 EXAMPLE

The methodical support is applied using the development of an active air spring (Figure 12). It is a project out of the Collaborative Research Centre SFB 805 and aims on the development of an active system which has a more flexible operation range in in comparison to a conventional spring-damper system in order to improve the driving comfort of a car (Hedrich et al., 2015).

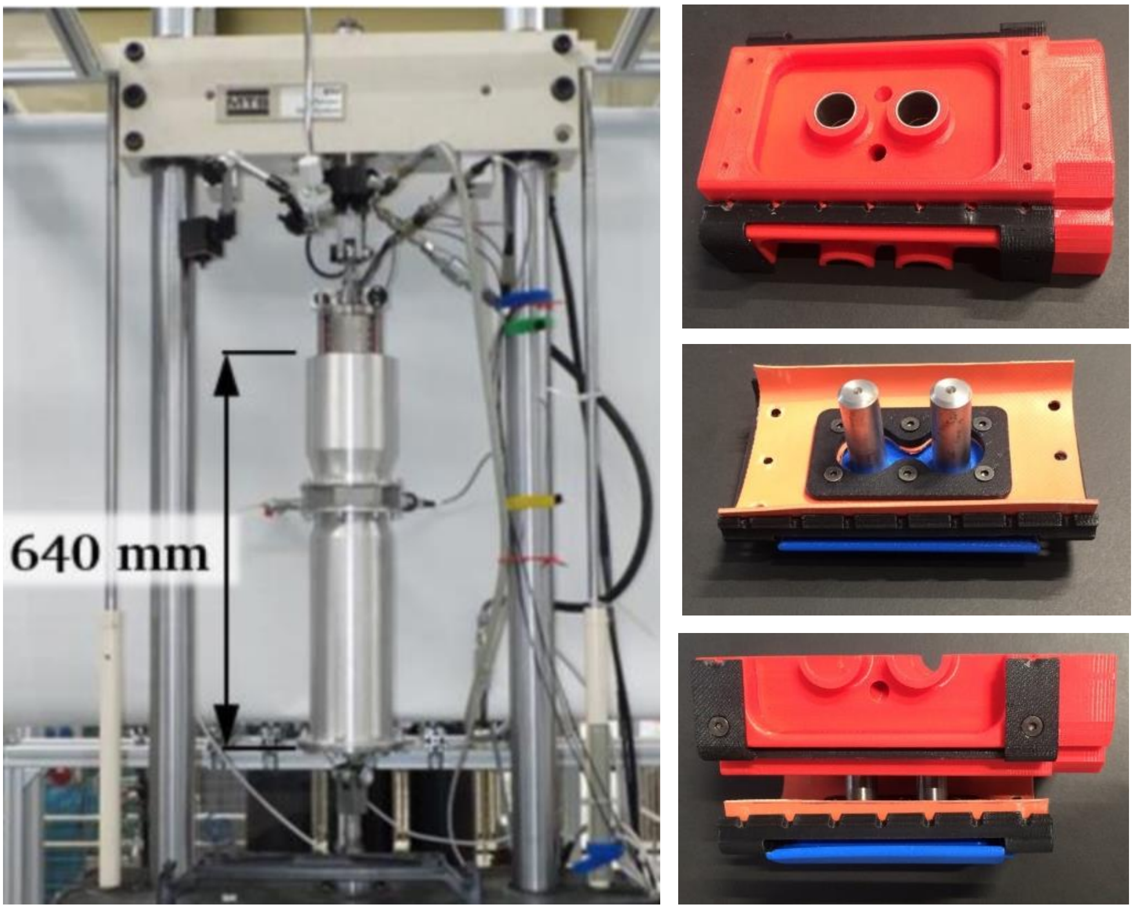


Figure 12. Active air spring (Hedrich et al., 2016)

The active air spring is simulated within a hardware in the loop environment in order to analyse its behaviour. An important component is the hydraulic actor (Figure 12), which changes the attenuation properties during drive. One important question was how to integrate the flexibility of the actor into the simulation model. It was realized with the help of a pressure build-up equation. After that, measurements were used to verify the simulated flexibility, whereby large deviations occur. In order to identify the reason for this deviation, the methodical approach is used.

First, relevant lifecycle processes of the actor are identified. Especially the production is important here, whereby the process *assembly of the membrane* such as the process *ventilation of the actor* are relevant.

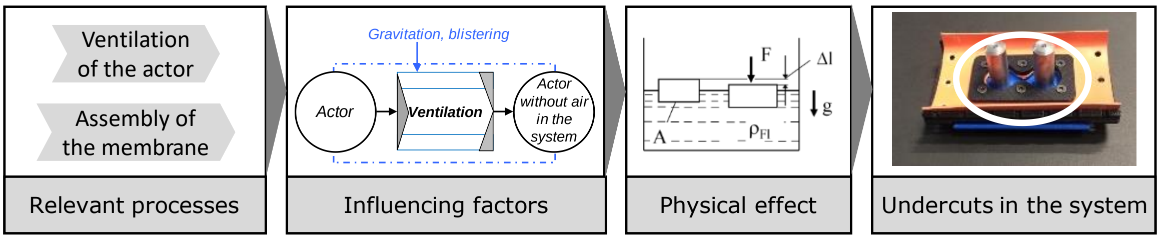


Figure 13. Results of the methodical support

During the next step, the process *ventilation* is regarded in more detail and the important disturbances *gravitation* and *blistering* are identified (Figure 13). Both influencing factors are analysed according to potential effects on the actor during the next step. They can be translated into the physical effect *buoyancy*. Referring this to the function of the actor, to convert hydraulic energy into mechanic energy, it is was recognised that its efficiency is reduced because of undercuts inside the actor. The viewing frame was adapted after the approach and the undercuts was integrated into the simulation model by defining disturbance volumes. With the help of that, deviations between measured and simulated values are reduced, so the level of uncertainty in the product model was reduced.

5 CONCLUSION AND OUTLOOK

This paper systematizes the process of product modelling to assist understanding of what the designer do during that process. With the help of that, a methodical support is developed which the designer can use to define a viewing frame for the product model. It is based on the function-process relationship and question, in which way the product behaves if identified influencing factors occur. By a systematic analysis of all function-process relationships, the level of uncertainty of a product model can be minimized. The support is especially usable if the functional aspect of the product is the focus of the analysis. If hierarchical or topological aspects of the product have to be investigated, the support is unsuitable. In further works the allocation of methods to the working steps has to be extended and evaluated using more examples.

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