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INTEGRATED PRODUCT AND PROCESS DEVELOPMENT BASED ON ROBUST DESIGN METHODOLOGY

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ABSTRACT

This approach shows a methodology which allows to systematically integrate the existing models and methods of Robust Design into the development of a product and its life cycle processes. To this end, a model of the design process is presented. At every stage of this model, the required documents are allocated generating a certain documentation.

It is essential that uncertainties, that occur within the life cycle of the product, are detected in order to control them. From the beginning of the very early phases of Robust Design a consistent uncertainty analysis is necessary. Therefore, product and life cycle process modeling is required in all phases. In order to generate the product and life cycle process models, a model-based integrated product and process development based on a combined product and life cycle process model is shown. Furthermore, an approach is presented to generate life cycle process models in the early phases based on the prognosis of product properties and the selection of the relevant properties for the prognosis of process properties.

Keywords: integrated product and process development, robust design, uncertainty, life cycle process model, combined product and life cycle process model

1 INTRODUCTION

Since Taguchi has developed the Robust Design methods [1], a lot of research concerning Robust Design has been done [2]. Many methods have been developed for the stages of Taguchi's Robust Design approach, especially for robust parameter design [3], [4], [5]. These methods are used throughout the final design phase, although there are some methods like Design Principles [6], [7] which can already be used in the conceptual design phase. Ullman [8] has developed methods to support the decision making in the design process. Methods like "Robust QFD" [9] and "robust product strategies" [10] can be used in the early phases of the process. So there are a number of Robust Design methods to support the development of robust products and processes. All of these methods can be used for controlling special uncertainties: uncertainties of the design process on the one hand and of the product life cycle process on the other hand.

Right now, an overall Robust Design methodology for a systematic design process to develop robust products and robust life cycle processes (material and production processes, use and reuse processes) does not exist yet.

The advantage of controlling uncertainties with Robust Design has already been proved [11] but the methods are not widespread in companies [12]. The Robust Design approach has great potential to maximize the profit of an enterprise, once the principles of Robust Design are used throughout the whole design process. In fact, the situation of Robust Design today reminds of the beginnings of the Quality Management approach.

To transport this potential approach into the industry, a methodology to integrate the thinking, models and methods into the existing design processes and into the divisions is required.

The basic construction for a Robust Design methodology in a model-based integrated product and life cycle process development is outlined in the following chapters.

2 ROBUST DESIGN PROCESS MODEL

In order to integrate the supporting working equipment of Robust Design, the methodology is based on a model of the Robust Design process (Figure 1) in which methods, models, specification techniques and tools can be arranged systematically.

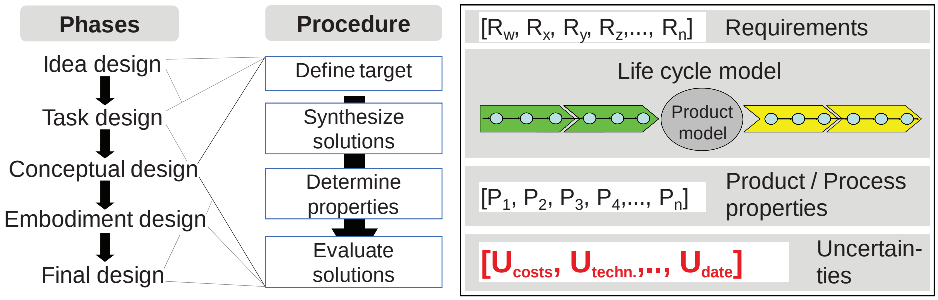

Figure 1. Model of the Robust Design process and its documentation

2.1 Phases of the Robust Design process

The model consists of phases and procedure steps. The phases “idea design”, “task design”, “conceptual design”, “embodiment design” and “final design” give structure and orientation to the design process and schedule the work that has to be done by the designer. The phases apply to the VDI-Guideline 2221 [13] and new cognitions of research on phases of the design process [14].

In the phase “idea design”, the designer finds himself in a situation that is often called “fuzzy front end”. At that time, he only knows that the enterprise has to generate profit and that a new product has to be designed for this purpose. Use processes, existing products and marketing information are analyzed to get a new product idea. In the Robust Design methodology, production responsibilities and enterprise strategies are also factors to be considered systematically. Thus the idea as the output of the phase “idea design” consists of a product description and a description of the life cycle processes.

In “task design”, the idea is analyzed with regard to the following aspects: the situation it is positioned in, the problem that has to be solved, things the product has to achieve in the use processes and things the production of the company has to achieve or the way the production has to be changed and expanded to produce the idea. The dominating document to be created in this phase is the list of requirements of the product and the life cycle processes.

Throughout the “conceptual design” phase, first approaches are developed to solve the problem by meeting the requirements. In product development, there are many methods, like structures of functions, for the systematic support of this phase. The solutions are called principle solutions and are often illustrated and described with principle sketches. The output of the concept phase is a concept of the product and life cycle processes.

Details of the individual parts of the solutions and the arrangement of these parts are defined in “embodiment design”. With these information, the realization of the concept becomes possible, as well as the production. The output of this phase is the design of the product and the life cycle processes .

All information concerning the embodiment of the product, overall production processes and their parameters have to be generated in “final design”. Outputs of the “final design” phase are documents like manufacturing drawings or working plans. With these documents, the production and assembling of the parts can begin. This stage is the end of the development of the product and life cycle processes.

2.2 Procedure steps in the phases

Every phase of the Robust Design process is structured with the four procedure steps “define target”, “synthesize solutions”, “determine properties” and “evaluate solutions”. These procedure steps indicate the work that has to be done by the designer. For all procedure steps that depend on the phase, special models and methods have to be used. The procedure steps are extracted from established design processes approved by Albers [15], Lindemann [16], Pahl/Beitz [17], Vajna [18] and Weber [19]. This sequence of processes is based on the methodological integration of cognition psychological analysis into design methodology [20], [21]. Thus they represent a “least common denominator” of fundamental process elements. This ensures that the models and methods of Robust Design methodology can be easily transferred to other design process models.

In the Robust Design methodology, the procedure steps are essential to the integration of special models and methods for analyzing and controlling uncertainties. Especially the procedure step "evaluate solutions" is directly connected to this and has great potential to be the most important procedure step of the Robust Design process.

The contents of the individual procedure steps are described now:

- In the procedure step "define target", the real target of development, depending on every phase, is defined. To this end, the situation is analyzed and the technical problem that has to be solved is defined. The description of the problem is carried out independently from solutions as it is required in modern design methodologies. That way the processor should be prevented from concentrating on existing solutions. He is brought to be independent from his own associated solutions and therefore to concentrate on understanding the real problem. This is the basis for the greatest possible solution space which should result in a diversity of solutions. Thus it is possible to generate a really better solution that is not only a further development of existing solutions. To define the target of the Robust Design process, it is crucial to determine which uncertainties of a solution should be reduced. The uncertainties to be respected are the results of the previous iteration step of the procedure steps. If it is the first step of iteration, there will only be a rough estimation of properties, probable uncertainties and the effects of the properties and uncertainties.
  The output of the procedure step "define target" is the representation of the target by the desired external properties [22] that can be derived from the requirements [23]. The uncertainties that should be reached in the desired properties have to be fixed as well. Thus the requirements do not only have to be described by the target value, but the tolerated uncertainties also have to be declared.
- In the procedure step "synthesize solutions", the solution space is filled with the greatest possible number of different solutions to the problem. The greater the solutions space, the greater the probability that one of the synthesized solutions nearly reaches the optimal solution. The solutions are often synthesized intuitively or by methods that support intuitive solution finding (brainstorming, brain writing). Methods for systematic solution development, like morphological analysis, are also used so that the solution space can be filled systematically. Systematic solution development is based on a variation of properties, followed by a systematic combination of the property variants. Throughout this procedure step, not only product models of the solutions are generated, but also possible life cycle process chains. The life cycle process chain is the basis for the identification of uncertainties. In order to identify the uncertainties that have to be considered a method like the uncertainty-mode and effects analysis (UMEA) [24] can be used.
  Furthermore, the controlling of uncertainties takes place in this procedure step. The products and the life cycle processes are generated with methods to control the uncertainties, like checklists, simulations and design principles, for an uncertainty optimized design.
  Results of the procedure step "synthesize solutions" are the generated solutions represented by their internal properties and the life cycle process chain. The internal properties reflect the inner structure of a solution. Thus, there is a different pack of internal properties for each different solution.
- In "determine properties", the basic task of the designer is to declare the internal properties of a product so that the resulting external properties fulfill the requirements. To compare the alternative solutions generated in the previous procedure step by their external properties, one has to predict from an internal property which value each alternative solution has in an external property. For this purpose, the internal properties have to be projected onto the external properties. Methods and instruments range from basic estimation to complex calculation, simulation like FEM and experiments with prototypes, depending on the phases in which the procedure steps have been treated. Every synthesized solution alternative has different expressions in the external properties because of the different internal properties and therefore has different abilities to fulfill the desired external properties. In addition to the calculation of the external properties, the uncertainties that can be reached in the external properties by the solution have to be calculated. Uncertainties at this point arise from the tools. These tools are based on models that are just a representation of reality. Therefore, the calculation cannot be done with any accuracy. The uncertainties of the internal properties also pass through to the external properties.

Outputs of the procedure step “determine properties” are the values of solution alternatives in the actual external properties together with the uncertainties which allow to reach these values in reality.

- By comparing the desired external properties with the actual external properties of one solution alternative, the ability of the solution to fulfill the desired external properties can be analyzed. The variance between actual properties and desired properties is calculated and interpreted in the procedure step “evaluate solutions”. Additionally, the uncertainty in reaching the actual external properties is interpreted. The interpretation of variance and uncertainty leads to an estimation of the solution based on its ability to fulfill the requirements. This is the base for the selection of some solutions and the rejection of others. Based on variance and uncertainty, one can decide whether to pass the phase and start the next one or pass through the iterative procedure steps once again. The important difference between the Robust Design process and other design processes is the fact that a solution alternative is chosen based on its target achievement and with respect to the uncertainties. A robust product with a robust life cycle process chain can be developed when the optimum between best target achievement and smallest uncertainty is reached.

  Outputs of the procedure step “evaluate solutions” are the selected solution alternatives as product and life cycle process models. The product and life cycle process models, with form and level of detail according to the phase are stated. The uncertainties, like epistemic and prognosis uncertainties of the Robust Design process itself and aleatoric uncertainties in product and life cycle process properties, are documented. This output is identical to the state at the end of the finished phase. Thus all information that is necessary to start the next phase has to be worked out and fixed in a documentation to constitute the start information of the next phase.

2.3 Documentation

The documentation generated throughout the procedure steps consists of requirements, a product and life cycle process model, properties of product and life cycle processes and uncertainties. The specification of the generated documentation depends on the phase that is passed. In the early phases, the product model and life cycle model is just described with the outer influences. Even in “task design”, “conceptual design”, and “embodiment design”, the product models like structure of functions and active principles can be seen in the product model pyramid [25], for example. In the phases “embodiment design” and “final design”, models like CAD or DMU are used. A model of the product life cycle for the early phases does not exist yet, life cycle process models for the later phases of development are not well defined and a level of detail corresponding to the phases does not exist. By demanding documents after every phase, the Robust Design process is a result-oriented design process.

Phases and procedure steps form the model of the Robust Design process. This model is based on existing design processes and it represents all phases of design which are necessary to develop a product and its life cycle processes, from the recognized claim of an enterprise to generate profit to the produced product. Thus it combines all the established steps of product development in one model and has the classic foundations of design methodology, so the established supporting methods of product development can be used in familiar ways. Additionally, in principle, the model has the ability to integrate special methods of Robust Design because of procedure steps that are intimately connected with analyzing and controlling uncertainties.

3 MODEL-BASED INTEGRATED PRODUCT AND PROCESS ENGINEERING BASED ON ROBUST DESIGN METHODOLOGY

3.1 Basis of model-based integrated product and process engineering

Uncertainties can only be estimated and calculated on the basis of a complete modeling of the life cycle process chain. Inside the Robust Design methodology, the uncertainties should be considered and controlled from the beginning of the development. Thus the model of the life cycle process chain gains an important position inside the Robust Design process, besides the product models, for analyzing product and life cycle processes with respect to uncertainties. Therefore, the life cycle process chain has to be considered in detail. It is therefore necessary to generate the chain independently from the phase of the design process and the degree of abstraction of the product models. Only by this approach, it is possible to get information about the effects of product-oriented decisions on material, production, use and reuse processes, and also about the way process-oriented decisions affect the product. With this bidirectional approach, it is possible to integrate the requirements from the product into the development of the life cycle processes on the one side and to integrate the requirements from these processes into the product development on the other side. This enables to declare the properties of the product and of the life cycle processes so that uncertainties are controlled and thus to develop robust products in combination with their robust life cycle process chain.

There are approaches to integrate aspects of the life cycle into product development, for example life cycle design or life cycle engineering. In life cycle design, the whole life cycle of a product is taken into account but not considered in a differentiated way, only certain aspects are further considered during the development. Similarly, the approach of life cycle costs considers the costs of the product throughout the whole life cycle. Besides manufacturing costs, the costs of use are integrated in order to assess the solution properties of the developed product. Inside the life cycle design, the design and life cycle processes are considered with functional units that represent standard scenarios of use. Eco-indicator values also reduce the environmental effect on one value.

In the calculation of bearings, typical use processes are represented with a load spectrum to simplify calculation, but the real use of the bearing and the use process can be very different from the load spectrum. Therefore, uncertainties arise when the spectrum is used. It is often postulated that the spectrum has the ability to reflect the load of the use process without respect to the uncertainties.

All these approaches for considering the life cycle processes in product development operate with typical processes, which are often represented with one mean value to approximate reality. Fully modeled process chains are not generated, but in order to control uncertainties, Robust Design needs this fully modeled process chain. Therefore, the product and process design needs an underlying method with the ability to generate this model.

Actual approaches of integrated product and process engineering focus on the principle target to consider all phases of the life cycle from material to reuse when the product properties are declared. The most popular approaches to implement methods for integrated product and process engineering are simultaneous [26] and concurrent engineering [27]. These approaches concentrate on integration by organization and information. To this end, it is established to build interdisciplinary teams from all divisions of an enterprise, like product planning, product development and process development. However, the results of simultaneous and concurrent engineering depend on the management abilities, the methodological competence and the team leader’s experience with the product and the market. Therefore, simultaneous and concurrent engineering do not provide a systematical generation of the life cycle process model.

3.2 Global model of integrated product and process engineering

For the parallel generation of the product and life cycle process models, it is necessary to form an integrated product and process engineering that enhances the approaches of simultaneous and concurrent engineering and that does not concentrate on integration of persons but has a central model-based structure. Based on the Robust Design process model, a model-based integrated product and process engineering combines all divisions and all aspects of the life cycle throughout every phase. So every phase of the design process is worked out in collaboration with product and process designers and all models of the product and life cycle process chain are generated together. Therewith, the life cycle process chain is not just another model that has to be generated, but it is the foundation for a model-based collaboration of all involved disciplines and persons because products, life cycle processes and their interactions have to be worked out and represented in a model. Information will be linked to generate the models and the key task is to consistently compile the missing information from all disciplines. Thus the development of the Robust Design process is an integrated model-based product and process engineering.

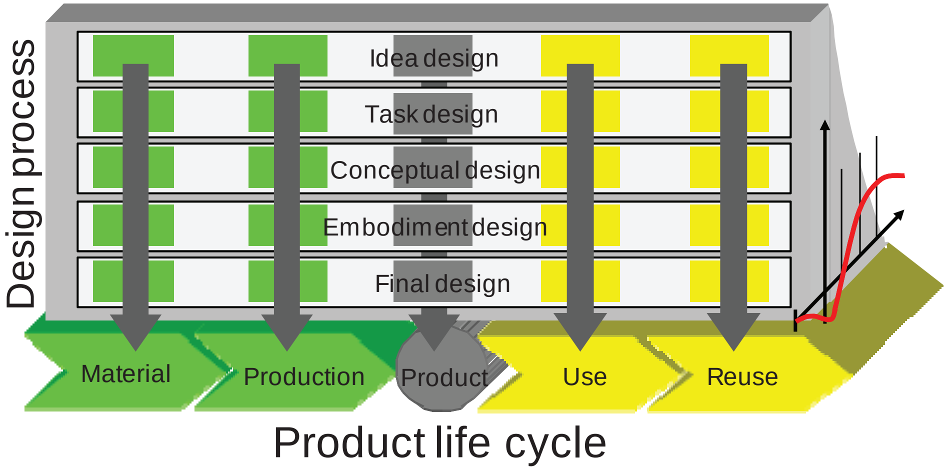

Figure 2. Global model of integrated product and process engineering

Additionally, the model-based integrated product and process engineering, as the model in Figure 2 shows, has the ability to integrate future requirements and plan products and life cycle processes all over the design process and also for following products and developments. It is therefore possible to control uncertainties that arise from the market throughout the product life cycle, like fluctuating product quantities inside development. Additionally, it is possible to plan which of the used technologies may be used by the following product with respect to environment parameters, like new technologies, competitors and the enterprise situation.

3.3 Methodological conflict of model-based integrated product and process engineering

When considering the phases of the Robust Design process in combination with the established product models of product development, it is obvious that it is not possible yet to deduce life cycle processes on the basis of a fuzzy conception of the product and an abstract product model, both based on uncertain information and used in the early phases of the product development. This means that it is impossible to generate a life cycle process model from the beginning of the design process. At the end of the design process, when the product is designed in detail, the life cycle process properties can be generated and life cycle process chains can be created (Figure 3). This reflects the traditional procedure: first, to create the detailed product and then to generate the life cycle processes. Additionally, simultaneous and concurrent engineering cannot create life cycle at the beginning of the design process.

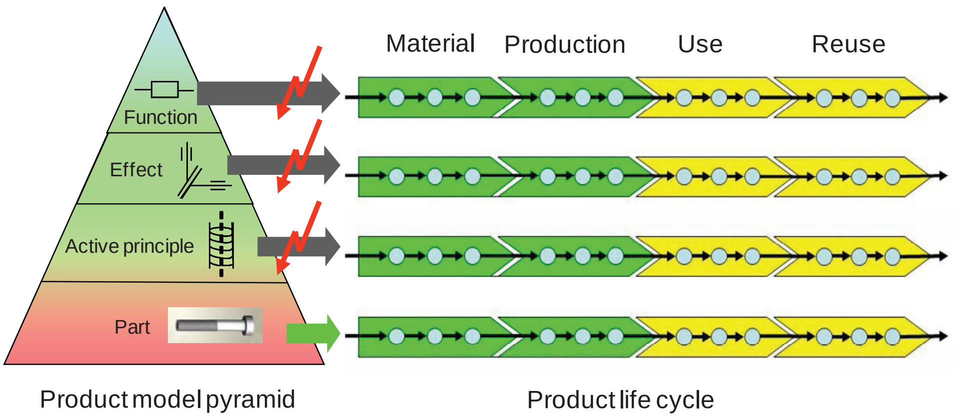

Figure 3. Methodological conflict of model-based integrated product and process engineering

So the basic problem of this model-based integrated product and process engineering is to generate the central model of the product AND the life cycle process model in the early phases together.
This problem can be understood as a methodological conflict. On the one hand, the process development needs at least a rough product design to declare and plan life cycle processes, but on the other hand, systematic product development defines the design as late as possible in the development process in order to consider as many different solution alternatives as possible with a minimal effort. Right now, the really concurrent product and process development is still avoided because product development cannot give enough information about the final design of the product to generate the life cycle processes in the early phases.

3.4 Approach for solving methodological conflict

Solving this methodological conflict seems to be the basic task to enable the model-based integrated product and process engineering of the Robust Design process. If enough information to define the life cycle model in the early phases is successfully generated, it will be possible to calculate uncertainties from the beginning of the development process and define arrangements to control the uncertainties.
A basic approach to solve the conflict is the idea of selecting relevant product properties from abstract product models in the early phases and making prognoses about the value of the more concrete product properties (Figure 4).

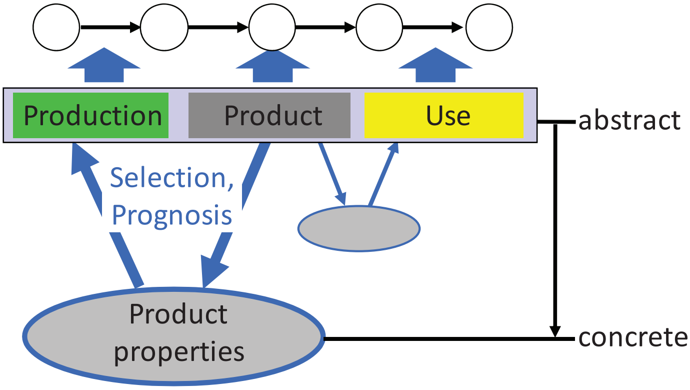

Figure 4. Approach of generating life cycle process model in the early phases

From these concrete product properties, the abstract life cycle processes properties may be selected and prognosticated. Based on these abstract process properties, the life cycle process models at the abstract level can be created. By using this procedure, it is possible to generate an abstract product life cycle in the early phases of the design process.

Product model and life cycle process model form a combined product and life cycle process model base and have to be established from the early beginning of the design process. Thus it is possible to create the combined product and process model as the central model which the Robust Design methodology is based on. It is a central task to generate it and to document the results throughout the design process. This will be associated with additional work, but the benefit of already knowing first life cycle processes in the early phases and therefore being able to make basic decisions in products and life cycle processes in the early phases with systematic respect to the uncertainties will justify it.

To control the uncertainties with Robust Design, it is necessary to answer the following questions: Where do uncertainties evolve from? What are the dimensions and results of the uncertainties? Which ones are problematic and have to be controlled? Additionally, the designer needs to know the way the uncertainties are linked as well as the parameters to control. So Robust Design needs an underlying method to analyze the product life cycle with respect to the uncertainties. The UMEA-method is used in this approach for this purpose, mostly in the procedure steps "synthesize solutions" and "evaluate solutions".

4 UNCERTAINIES IN THE PROCEDURE STEPS

4.1 Arrangement of uncertainties in the procedure steps

In the procedure steps of the phases of the Robust Design process uncertainties based on the model of the life cycle process chain can be calculated and used to evaluate the quality of solutions. The uncertainties, which are to be considered, exist unavoidably whenever either solutions are developed together with their life cycle, models are generated, properties are declared, or decisions are made. With the aid of the modeling of the life cycle and the use of the UMEA it is possible to observe them and by this to gather more information for the development.

Based on their definition and their consideration the uncertainties can be arranged in the procedure steps as illustrated below (Figure 5):

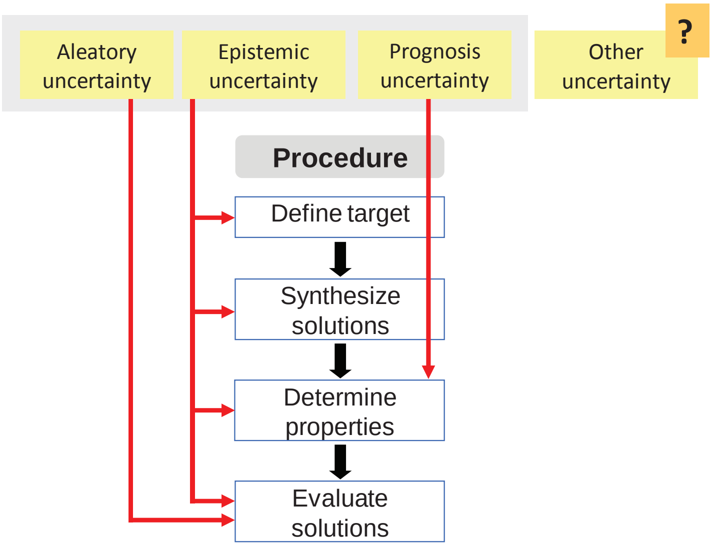

Figure 5. Arrangement of uncertainties in the procedure steps

Aleatory uncertainties

Aleatory uncertainties appear in products and life cycle processes which is obvious since the properties are generated in a real process of production. Aleatory uncertainties like noise-factors and process parameters influence the production process and therefore the manufactured product properties. These uncertainties can affect non-robust behavior in the use processes. Additionally, other aleatory uncertainties appear throughout the use processes like noise factors and the use-process parameters. The Robust Design process together with the modeling of life cycle process is able to consider these uncertainties.

Aleatory uncertainties are considered and evaluated particularly in the procedure step "evaluate solution".

These uncertainties in product properties can increase as well as decrease troughout the processes. For example, the cutting of a sheet part in a cut process causes high uncertainty in the product property "straightness". However, by applying the process of straightening this uncertainty can be reduced to a tolerated value. Overall it is investigated how the uncertainties in the life cycle processes are linked to uncertainties in product properties and how these might accumulate in the following processes. The UMEA is closely linked here.

By synthesizing the process chains in contact with the product properties in the robust design process, it is possible to configure the life cycle process chain together with the product. As a result, aleatory uncertainties of the production processes have no effect on the product and aleatory uncertainties of the product have no effect on the use processes. Hence, a robust product with a robust life cycle is developed. In order to realize this, life cycle processes, their order and their parameters have to be determined in dynamic interaction with the declaration of the product properties. This parallel and interacting procedure is the strength of the presented model-based integrated product and process engineering.

Epistemic uncertainties

Epistemic uncertainties result from the usage of more or less complete or correct models in every procedure step of the design process. The models are the work equipment used by the designers in the procedure steps. The assignment of the models is based on their characteristic limitation. Often these limitations can neither be specified nor even rough estimated. At this point, it is uncertain whether the used model possesses an acceptable quality which is able to meet the considered circumstances. A popular example are the equations of Euler within light-weight constructions, which allow an approximation of the buckling load of a column. In order to get results from the equation that represents reality in an acceptable way the slenderness ratio has to be calculated. During the design process and particularly in the early phases it is often only possible to obtain a rough estimation of the value of the slenderness ratio. For instance, if the diameter of the column is not declared it is uncertain whether the equations of Euler can be used.

Epistemic uncertainties are to be treated in every procedure step for all the used models to make a prediction of probability, whether the declared properties and their uncertainties are correct or not. Throughout the procedure step "evaluate solution" this prediction of probability is one basis for making decisions for robust products and life cycle processes.

Prognosis uncertainties

Prognosis uncertainties are related to the prognosis of product and life cycle processes properties and result from incomplete information. These uncertainties directly influence the declaration of solution properties. Especially in the early design phases values of properties from the solution alternatives have to be estimated without the knowledge of either concrete equations or the circumstances of the solution. This estimation is often based on specific experience of the decision makers and a gut feeling. Today the estimation is often carried out in teams of designers. Throughout the discussion, this team tries to include all aspects used for a reasonable estimation and by this to reduce uncertainty. If uncertainty is subjectively low it will be appreciated with a "good feeling". However, low uncertainty requires great effort of many designers, and for this reason estimations with high uncertainties are often accepted. Thus, in the following design process the results of those uncertain estimations become basis of following considerations and following estimations. Often the uncertainty of the basis is no longer considered which causes the estimation to be seen as certain and fixed. If further estimations and results are conflicting in the following design steps wrong estimations can be detected and corrected. If wrong estimations are not detected in the early phases, their negative results will arise in later phases and might provoke cost-intensive iteration steps in previous phases in the operating design process. Wrong estimations that are not detected throughout the entire design process are highly critical because they can have effects within the use processes.

Within the Robust Design process the denotation of the uncertainty is demanded when the estimation is made and prognosis uncertainties have to be dealt with in the procedure step "determine properties". Now an estimation with high uncertainty can be used in following processes and the results based on it are examined critically. If uncertainties are indicated these can be reduced. By this procedure, faults caused in uncertain estimations are avoided.

At this point of research, it has not been clarified yet whether other uncertainties have to be taken into consideration and whether the approach has to be extended. However, in previous research there has been no indication for it.

4.2 Behavior of uncertainties throughout Robust Design process

Based on the arrangement in the procedure steps the different uncertainties develop throughout the Robust Design process.

The number of aleatory uncertainties increases throughout the design phases due to the increasing level of detail of the product models and the increase of properties, which comes along with it. Furthermore, the increasing level of detail of life cycle process models causes an increase of the number of uncertainties in the process models, which have to be considered.

The uncertainty of one property can increase, decrease or stagnate. By trend the value of every uncertainty increases due to advancing concreteness and advanced information.

In the early phases of development models with a low level of detail and a number of simplifications are used. These models need minimal time, personnel and technical resources to be implemented on a solution in the early phases when many different solution alternatives have to be considered and evaluated based on the same models. If detailed models were used the effort would be immense. During the subsequent phases models become more concrete and therefore epistemic uncertainties reduce continuously. Nevertheless, these uncertainties still exist in the last state of product and process documentation and will not disappear since a model is always only an image of reality and therefore never fully accurate.

Throughout the Robust Design process information increases, uncertain estimations are reduced and accurate calculated values can be used. For example, the early estimation of costs is made with little and imprecise information about parts, materials and production processes. It is impossible to make accurate predictions of costs and the prognosis uncertainty is on a high level. In later phases detailed information exists and the costs can be calculated in detail. At this point the prognosis uncertainty of a cost prediction is on a low level.

5 CONCLUSION

The modern design process can be represented through an overall model of the design process. This model consists of phases, procedure steps and documentation. It contains all established phases and despite the fact it is extended with modern phases it is applied in the early phases of the design process. The procedure steps are based on established problem solving steps. As the approaches of product and process engineering demand, this extended design process enables one to integrate all aspects of product and life cycle processes and to return these as requirements to product and life cycle processes within all phases. This feedback is based on a model-based integrated product and processes development. The arising problem of a methodological conflict can be solved with an underlying method for selection and prognosis of product and life cycle process properties. By this it is possible to work out product and life cycle process models parallel in all design phases. The presented design process solves many of the problems simultaneous engineering and concurrent engineering are faced with and forms a basis for a new integrated product and process engineering.

At this point, the present design process is a representation of a general design process and not a robust design process in particular. However, by examining the production and use process one is able to analyze and control uncertainties arising over the product and life cycle process development since uncertainties and their effects can only be observed by a consistent life cycle process modeling. Also some of the procedure steps show direct connections and great potential to analyze and control the uncertainties. Therefore methods like the UMEA have a central position and can be integrated into the design process. The uncertainties are often the main causes for a possible failure of design projects [28], [29]. By controlling the uncertainties the design process forms a Robust Design process. This Robust Design process possesses its own documentation. The standard document structure is extended with documents based on models and methods particularly used for Robust Design. By the arrangement of the different uncertainties in the created procedure steps it is shown, that this Robust Design process has the ability to consider all arising uncertainties and can control them in different steps. For this reason, the entire concept represents a Robust Design methodology consisting of a design process model to describe the design procedure and integrated models, methods, tools and any other supporting working equipment.

The following research will contain the arrangement of existing models and methods in the design process. In addition, it will create both a method for model-based product and process development in all design phases on the presented approach and a development of new methods for using new technologies in robust design. The research is financed by the "DFG – Deutsche Forschungsgemeinschaft" in the CRC 805 "Control of Uncertainty of Load Carrying Systems in Mechanical Engineering".

REFERENCES

[1] Taguchi G. *Taguchi on Robust Technology Development: Bringing Quality Engineering Upstream*, 1993 (ASME Press, New York).

[2] Arvidsson M. and Gremyr I. Principles of Robust Design Methodology. *Quality and Reliability Engineering International*, 2008, 24, 23-35.

[3] Robinson T., Borror C. and Myers R. Robust Parameter Design: A Review. *Quality and Reliability Engineering International*, 2004, 20, 81–101.

[4] Rötzer I. Der Realität so nah wie möglich. *Fraunhofer Magazin*, 2008, 2, pp. 46-47.

[5] Albers A., Enkler H.-G., Maier T. and Weiler H. Robust Design processes with CAD based finite element models. In *International Conference on Engineering Design, ICED'07*, Paris, August 2007.

[6] Andersson P. A semi-analytic approach to robust design in the conceptual design phase. *Research in Engineering Design*, 1996, 8, 229–239.

[7] Andersson P. On robust design in the conceptual design phase – A qualitative approach. *Journal of Engineering Design*, 1997, 8, 75–90.

[8] Ullman D. *Making Robust Decisions: Decision Management for Technical, Business, and Service Teams*, 2006 (Trafford Publishing, Victoria).

[9] Kim K.-J., Kim D.-H. and Min D.-K. Robust QFD: Framework and a Case Study. *Quality and Reliability Engineering International*, 2007, 23, 31-44.

[10] Gausemeier J., Fink A. and Schlake O. *Szenario-Management*, 1996 (Carl Hanser, München).

[11] Yassine A. Investigating Product Development Process Reliability and Robustness Using Simulation. *Journal of Engineering Design*, 2007, 18(6), 545-561.

[12] Gremyr I., Arvidsson M. and Johansson P. Robust Design Methodology: Status in the Swedish Manufacturing Industry. *Quality and Reliability Engineering International*, 2003, 19, 285–293.

[13] VDI-Guideline 2221: *Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte*, 1993 (Beuth, Düsseldorf).

[14] Jetter A. *Produktplanung im Fuzzy Front End*, 2005 (Deutscher Universitäts-Verlag, Wiesbaden).

[15] Albers A. and Mebold M. *Spalten Matrix – Product Development Process on the Basis of Systems Engineering and Systematic Problem Solving. The Future of Product Development*, 2007 (Springer, Berlin).

[16] Lindemann U. *Methodische Entwicklung technischer Produkte*, 2007 (Springer, Berlin).

[17] Pahl G. and Beitz W. *Konstruktionslehre: Methoden und Anwendung*, 1997 (Springer, Tokio).

[18] Freisleben D. and Vajna S. *Integrierte Produktentwicklung, Gestaltung und Optimierung von Produktentwicklungsprozessen mit einem wissensbasierten Vorgehensmodell*, 2001 (Universität Magdeburg Lehrstuhl für Maschinenbauinformatik, Madgeburg).

[19] Steinbach M., Botta C. and Weber C. Integrierte Entwicklung von Product-Service Systems. *Werkstattstechnik online*, 95, 7/8, 2005, pp. 546-553.

[20] Frankenberger E. *Arbeitsteilige Produktentwicklung: empirische Untersuchung und Empfehlungen zur Gruppenarbeit in der Konstruktion*, 1997 (VDI, Düsseldorf).

[21] Dörner D. *Die Logik des Misslingens – Strategisches Denken in komplexen Situationen*, 2000 (Rowohlt, Reinbeck).

[22] Wäldele M., Hirsch N. and Birkhofer H. Providing Properties for the Optimization of branched Sheet Metal Products. In *International Conference on Engineering Design, ICED'07*, Paris, August 2007.

[23] Chahadi Y., Wäldele M. and Birkhofer H. QFD – A link between customer requirements and productproperties. In *International Conference on Engineering Design, ICED'07,* Paris, August 2007.
[24] Engelhardt R. Uncertainty-Mode- and Effects-Analysis – An Approach to analyse and estimate Uncertainty in the Product Life Cycle. In *International Conference on Engineering Design, ICED'09,* Stanford, August 2009 (intended).
[25] Sauer T. *Ein Konzept zur Nutzung von Lösungsobjekten für die Produktentwicklung in Lern- und Anwendungssystemen*, 2006 (VDI, Düsseldorf).
[26] Eversheim W., Bochtler W. and Laufenberg L. *Simultaneous Engineering. Erfahrungen aus der Industrie für die Industrie*, 1995 (Springer, Berlin).
[27] Bullinger H.-J. and Warschat J. *Concurrent Simultaneous Engineering Systems. The Way to Successful Product Development*, 1998 (Springer, Berlin).
[28] Chalupnik M., Wynn D., Eckert C. and Clarkson J. Understanding design process robustness: A modelling approach. In *International Conference on Engineering Design, ICED'07,* Paris, August 2007.
[29] Möhringer S. The relation between project risks and robustness of design – a crucial factor of success in plant engineering. In *International Design Conference, Design 2008,* Dubrovnik, May 2008, pp.457-464.

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