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PROCESS BASED UNCERTAINTY ANALYSIS – AN APROACH TO ANALYSE UNCERTAINTIES USING A PROCESS MODEL

Hermann Kloberdanz, Roland Engelhardt, Johannes Mathias and Herbert Birkhofer
Technische Universität Darmstadt, Germany

ABSTRACT

Uncertainties in technical systems in the field of mechanical engineering occur in all processes throughout the entire life cycle of a product. In general these uncertainties are understood as deviations from the process and product properties. This fact makes it necessary to develop methods for detailed analysis of the occurrence of uncertainties.

Since uncertainties occur in processes, they can be analyzed based on a detailed process model. Therefore a new process model is developed by systematic completion of known process models. Based on this process model uncertainties can be identified easily and almost completely. It is possible to use the model to analyze uncertainties deriving from process interactions too. In addition the process based approach delivers a structured understanding of the emergence of uncertainties. Thus it forms a promising basis for the development of methods and tools to analyse uncertainties in general. The developed model is restricted to technical processes at the moment. The process based uncertainty analysis is one method in the Uncertainty Mode and Effects Analysis – methodology (UMEA) beside others. Nevertheless the process model forms an elementary basis for the UMEA methodology for describing, evaluating and treating uncertainties in a comprehensive manner.

Keywords: Process, uncertainty, analysis, process model, product life cycle, method

1 INTRODUCTION

Products are developed and produced by manufacturers for a certain purpose and used by the customer in order to gain a benefit from them [1] [2]. The products, however, do not always fulfil awaited expectations.

- For example, individual products of a series can display impaired performance if, due to incorrectly manufactured components or an unfortunate interaction of production tolerances and/or material properties, the total functioning is degraded. Similar cases can also occur if the production process is changed or different materials are used. In the worst case, a product failure which ultimately leads to a hazard, can present itself.
- In new developments, it can happen that products do not achieve the values prognosticated by the developers. Further, customers' requests may be incorrectly assessed or overlooked. Both errors usually lead to the situation that neither customer expectations nor the expectations of the enterprise are fulfilled. Serious cases are described as "product flops."
- In other cases, the product use changes, e.g. due to extending the application of the product to other areas. Or a changed competitive arena forces a changed product use. Although the specifications of the originally planned use may have been met, these new situations cannot be mastered satisfactorily. The product ages and perhaps must even be taken off the market.

In summary, the situation that arises when products do not fulfil expectations in some way is called "uncertainty" in this document.

2 CONTROL OF UNCERTAINTIES

This article is a part of a research project whose goal it is to better control uncertainties relating to technical systems in mechanical engineering contexts.
In order to analyze the occurrence and effect of uncertainties, it is necessary to formalize the observed situations. The default of expectations can be formally described as a deviation of product functioning from the expectancy values.

- For example, a malfunction of the product during scheduled mechanical load can be perceived as a deviation of properties of load-carrying capacity.
- In this regard, the characteristics are not limited to technical criteria, but also encompass economic and ecological aspects. If a product is too expensive in relation to the benefit it generates for the user, e.g. due to high manufacturing costs or too low an efficiency factor, it will not fulfill the economic expectations due to these cost characteristics. The same would also apply to the emission characteristics of the product and ecological expectations.
- If customer perception of value as well as customer expectations are to be considered more comprehensively, the delivery details, such as the delivery deadline of the product as it relates to the availability expectations of the customer, must likewise be considered.

As already evident from the explanations in the examples, the uncertainty definition is based on a very general definition of properties. Properties generally cover all dimensions and data which describe the product, its production and its use, etc. [13.]

2.1 Uncertainty in engineering and product development

In the engineering sciences, the word “uncertainty” is mainly used to describe uncertainty in materials and uncertainty in stress, including the statistical deviation [3]. These are sophisticated and demanding procedures of probability calculation. In industrial applications, however, reliability analyses are primarily performed on limited aspects [4] [12].
In engineering spheres, there is no clear definition of uncertainty. Uncertainty is often associated with reliability, risk or tolerance. [5]
Uncertainty is particularly relevant for the approach of Taguchi [7]. He considers monetary losses arising from discrepancies during the entire product life cycle. Taguchi accordingly applies targets of functional characteristics to all deviations [8].
Here uncertainties are understood as deviations from the process and product properties in general. This takes into account properties of existing products as well as forecasts of properties based on modeling of technical, environmental and economic aspects during product and process development [14] [15].

Several different basic types of uncertainties may occur:

- The undesirable functioning of the product during use or production is caused by the fact that the product properties were insufficiently defined during the development process.
- The undesirable functioning of the product is caused by deviations of the product properties from their planned values. The deviation of the product properties may have been caused by deviations in the production processes.
- The undesirable product functioning is caused by the fact that the product is used during unplanned and/or modified processes or in a process environment for which it was not intended.

One can easily recognize that it is a fundamental characteristic of uncertainties that they only become relevant in connection with products and processes in which the product is involved. (In short, one can say that uncertainties develop during processes.) Therefore it stands to reason that one would analyze the emergence of uncertainties with the help of processing concepts.
Thus, all processes must be considered in the product life cycle - production processes, operational processes, sales processes, recycling processes etc. Only in this way can the uncertainties of all

substantial characteristics be considered - load-carrying capacity, performance, quality, costs, life span, economy, delivery deadline etc.

3 Process Modeling

A process is defined as a time-dependent transformation of the initial state of a operand into a changed final state (also designated as initial condition and final condition).
Although this definition applies to practically all describable change processes, the observations here are limited to technical processes. Business processes, sociological processes or similar non-technical processes have not been considered. (A case-by-case transfer of the examination to non-technical processes such as development processes are planned for a later time).
In the literature many different process models are defined:

- Very simple black-box models describe only input-output relations.
- The SADT model incorporates resources and control information.
- In the processing concept in compliance with the DIN, the process environment is included.
- Heidemann describes a model of technical processes which incorporates different implementation stages and in which product and process are differentiated. [9]

The process model of Heidemann has proved very practical for modelling technical systems. The different models of Heidemann accommodate to special focus of processes. Therefore they are more or less detailed. [11] (Figure 1)

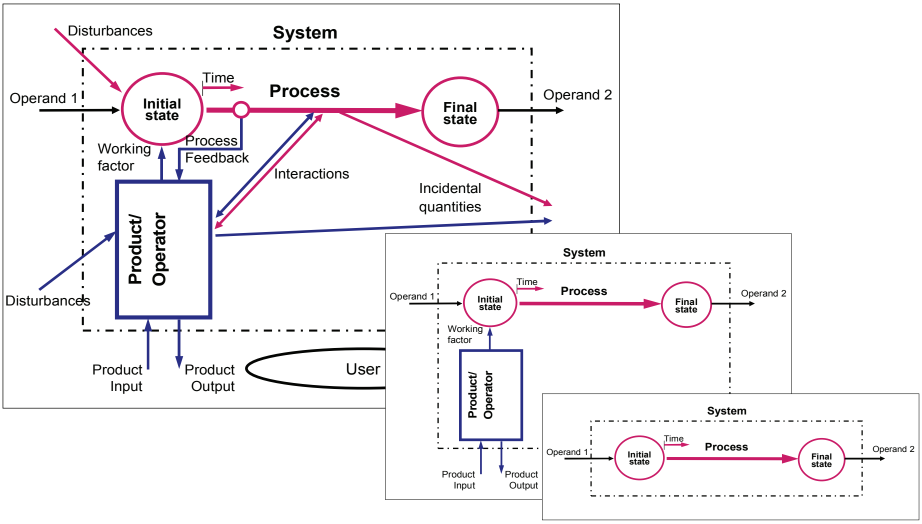

Figure 1: Complete, reduced and simple process model

The process models are adapted in each case to the focal points of processes and are therefore differentiated to varying degrees. The detailed process model according to Heidemann represents one of the most extensive models in general (Figure 2) [9].

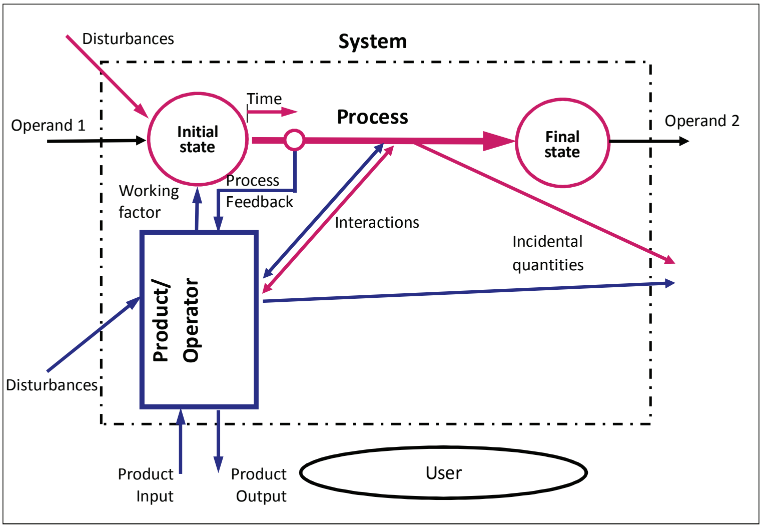

Figure 2: The complete process model for detailed processes analysis [9]

Since the process model according to Heidemann serves as a starting point for the further developments, some characteristics are pointed out here:

- The model is used for the development of new products (for product innovation). It therefore illustrates application processes. In particular it is used for the clarification of tasks and detection of requirements.
- A fundamental aspect of this model is the differentiation between the application process of the customer and the product that the company produces for this purpose. To emphasize the differentiation clearly, the product (as a black box) and the process (as an arrow) are illustrated as differently as possible and the product does not directly affect the process, but instead the initial state. This representation is frequently perceived as unusual by newcomers.
- The model distinguishes between the product and process elements and the environment via the system border in order to clarify the product boundaries.
- To limit the complexity, the model is confined to the relevant aspects of the application for product innovation and is therefore not complete.

Basing on Heidemann's model, a more widely differentiated model was developed, which satisfies in a generally valid manner the requirements of comprehensive and detailed uncertainty analyses. At the same time, attempts were made to integrate the elements of many models well-known from the literature into this model in order to define a generally valid model as completely as possible.

3.1 General model of technical processes

Initiated by the intention of being able to analyze uncertainties comprehensively and in a generally-accepted fashion, a model of technical processes was developed by means of systematic completion.
The development of the new process model was based on Heidemann's model. It should cover all possible process characteristics that can be relevant for a process analysis, as well as all possible models already used. The model should be kept as generally applicable as possible and should fulfill the requirements of detailed uncertainty analyses. Therefore besides the states of the operand, its changes and the necessary means, all kind of surrounding elements are considered. These are

necessary resources, the interfering and observing user, related processes and the environment in general. All these elements are systematically connected to each other as far as sensible. Thus an almost complete model should be formed.
At the same time it was attempted to integrate the elements of many established models from literature, the goal being the definition of the most generally-applicable model possible:

- Differentiation between operand and its describing conditions, process and working means: These elements are represented in different form.
- Representation, which is as similar as possible to models already in use: The actual process is most frequently represented as a block arrow.
- Applicable to as many types of processes as possible, in particular for production and application processes: Uniform designation of the work equipment (can represent both product and means of production).
- Clear distinction between the regarded product-process system and the environment, illustration of the process environment as completely as possible: users, resources and environment were defined as equal, plane elements, which are distinguished from the product-process system by the system border.
- Illustrate intended and unintended relations as completely as possible: relations between all elements are represented by arrows, as far as this is meaningful.

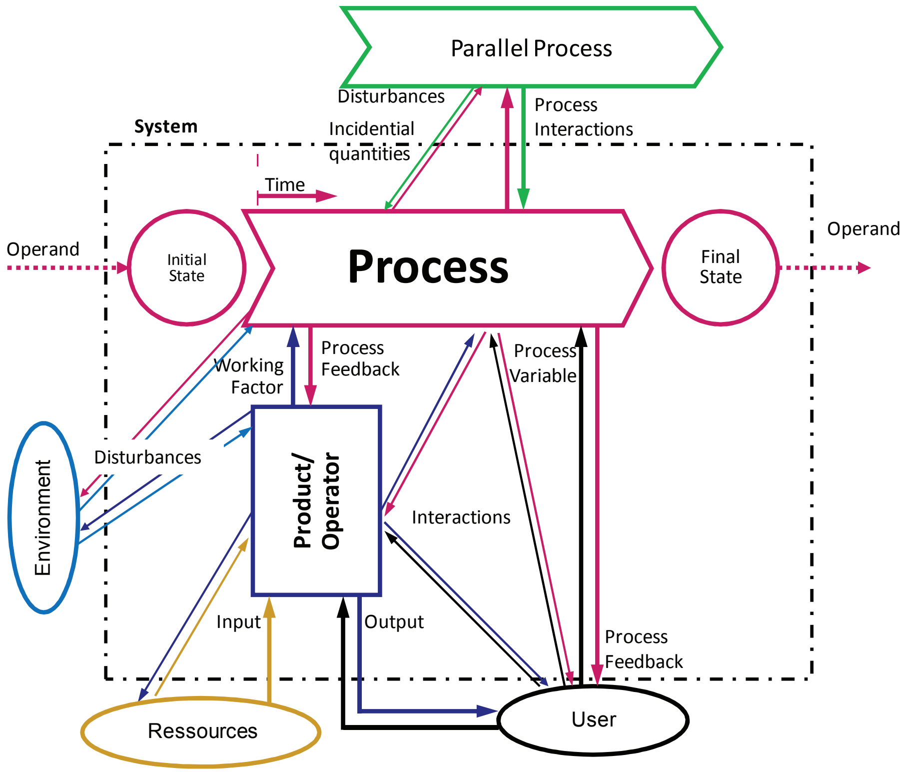

Figure 3: The extended process model to analyse uncertainies

The new process model consists of the following elements:

- **Process:** Here the distinction is made between the process as a time-dependant transformation and the procedure indicating the underlying basic technologies.
- **Operand, initial state, final condition:** The operands represent the inputs and outputs and are changed in the process. The change is described by the indication of the beginning and end conditions. The conditions describe the properties of the operands. In mechanical engineering processes, the operands usually are real objects which are physically or chemically altered. In production processes, the operands are represented by the product or its components.
- **Working means:** The working means provide effect variables, with which the process is carried out, i.e. the characteristics of the operands are changed.
- **Environment, resources and users:** Resources are used to create the effect variables, e.g. energies and materials from the process environment are used and/or brought there. The work equipment is usually controlled by the user (operator). Often the user directly observes the process. He can also intervene without using the work equipment. (To simplify the model human powered working means are not shown explicit. In these cases the user provides the power and takes the part of the resource). The intended relations between environment, user, resources and process or working means are represented by vertical or horizontal arrows. In substance these are input parameters and feedbacks.
- **Disturbance variables, secondary variables, interactions:** working means and processes unintentionally interact with each other and with the environment, user and resources. These disturbance variables, secondary variables and interactions are illustrated as diagonally running arrows. For the uncertainty analyses, these relations play a substantial role. Therefore, all possible unintentional relations were systematically integrated.

First applications show that the created model is so generally formulated that it can also be used for non-technical processes to a limited extent.

3.2 Uncertainties in the process model, General approach

Since uncertainties occur in processes [10], it seems sensible to analyze the occurrence of uncertainties with the help of process models.
For product developers, uncertainties which develop during processes in which the regarded product is involved are of interest. These are all processes in the product life cycle; both production processes and application processes.
Uncertainties can be interpreted as deviations of the process result, which is described by the final conditions of the operands after the execution of the process:

- During application processes the product does not provide the expected effect variables, so that the process result (the use) is not reached. The product behavior does not correspond to expectations.
- During the product manufacturing, deviations in the production process occur so that the production result (the product properties) deviates from the expected one. The product does not correspond to expectations.

The analysis of the emergence of uncertainties is of special interest for the product development.
Similarly as with the error analysis, it is decisive that the causes of uncertainties be known. A multi-level approach in hierarchical structures similar to fault tree analyses is pursued in the error analysis. Finally it is then not differentiated whether the deviation itself or the cause represents the error.
Similar to the error analysis, deviations in the process itself, direct influences on the process or indirect via the working means causing a change of the process result (final conditions of the operands) are to be interpreted as uncertainties. Thus, uncertainties can be caused by deviations in all process characteristics i.e. in all elements of the process model representation. All these deviations should be understood as uncertainties.

3.2 Concept for the determination of uncertainties in processes

If it is assumed that all elements and relationships in the process model can contain potential uncertainties, they can be identified very easily in a structured fashion by systematic layout of the process model.
In principal uncertainties can occur as follows.

- prerequisites of the process are not existent
- working means does not provide the necessary working factors
- inputs or process feedback deviate
- disturbances affect the process or the working means
- affects of secondary values on the surrounding of the process are not acceptable

Using the developed process model all these typical uncertainties can be easily assigned to the process elements.
During the structured ascertainment of uncertainties, they are not assigned according to the typical emergence. Here the aspect of localization of the uncertainties is chosen as main principal of arrangement. This is more easy to understand for newcomers. Here it is distinguished between outer uncertainties and internal uncertainties (Figure 4). (Also an ascertainment according to different criteria is possible, even using two different criteria in form of a portfoliodiagram.)
In order to describe the illustration, the example of the process "creating a hole in a concrete wall using the procedure percussion drilling" is used. The percussion drill represents work means. To limit the extent, the example will only be used as required and only typical uncertainties will be discussed in the application processes.

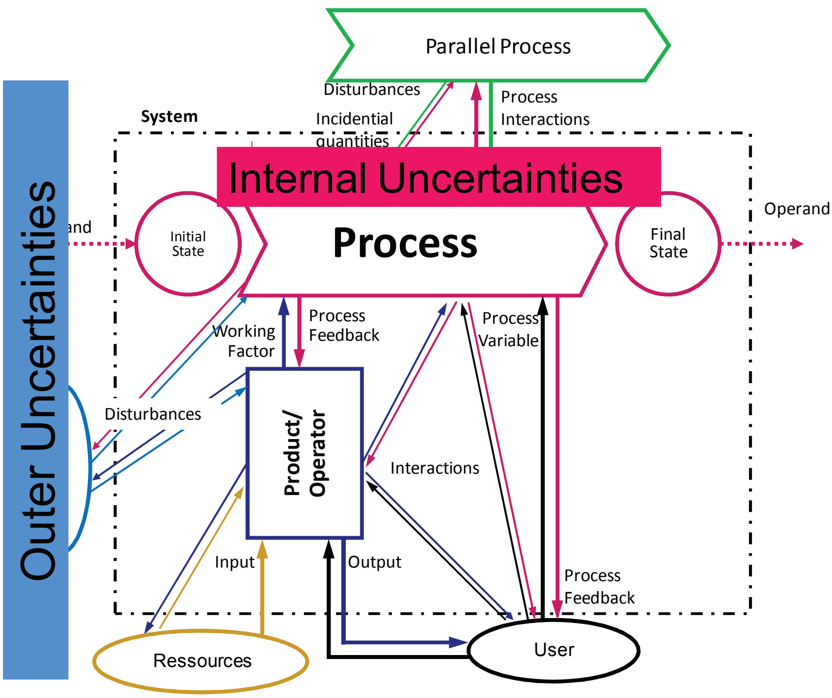

Figure 4: Internal and Outer Uncertainties.

Internal uncertainties:

Internal uncertainties are caused by process deviations or by effects, within the system border:

- Uncertainties by process deviations typically develop if the procedure exhibits an unexpectedly strong nonlinear behavior and the process is operated within such a range. For example, the drilling speed cannot be increased at will along with the impact energy.
- Uncertainties due to an insufficient definition of the effect variables during the product development. The success of pneumatic percussion drills is based essentially on the fact that the drill rotation speed, impact rate and impact energy were differentiated and defined consciously.
- Uncertainties due to deviation of the behavior of work equipment.
  Typical for this are deviations caused by wear occurrences in work equipment. Non-linearities such as thermal expansion, flexible deformations or compressibility cause uncertainties just as frequently. Uncertainties in work equipment express themselves in the form of insufficient effect variables such as deviations of the impact frequency and impact energy in the example process.
- Uncertainties due to the interaction of the process and work equipment. These uncertainties are particularly critical in the context of the product development, as the interactions cannot be avoided and they are easily overlooked. For example, the drill dust can damage the drill. On the other side, the drill can make the wall dirty.

Outer uncertainties:
Outer uncertainties are caused by effects which transcend the system border.

- Deviations in intended values between process (direct) or work equipment (indirect) and the process-surrounding elements (users, resources and process environment). Uncertainties typically develop if the power supply or supporting forces are not sufficient, as can be the case with percussion drilling. Large uncertainties also exist because of incorrect operation by users.
- Uncertainties due to disturbance variables because of effects of the surrounding elements on the process or work equipment. These are the most frequent uncertainties. Product affection is particularly typical. For example, high ambient temperatures, water (rain) or electromagnetic fields can affect the function of the drill.
- Uncertainties also result from secondary effects, which are defined as effects of the process or work equipment on the surrounding elements. Usually no deviations occur in the process result; however it can happen that the process is no longer accepted. For example, dust, noise or tremors can be perceived as unacceptable.
- Uncertainties can result of deviations in conditions of operands described in the initial state. For example the drilling process can be affected by the stiffness of the wall which causes longer drilling time and often an enlarged diameter of the hole.

The operands play an important part in analyzing uncertainties in processes because the final state in one process is the initial state of a following process. Thus, uncertainties are connected according to the network of processes. During a complete uncertainty analysis it is not sufficient to look at singular processes. Instead the whole process life cycle has to be considered, which can be represented by an network of processes. Looking at the drilling process it might be possible that the fixing of an object to the wall will fail later caused by an enlarged diameter of the hole.

Processes are not only connected by the operands but also by direct intended or unintended interactions. Especially these are processes performed simultaneously or process for preparing the working means as service or cleaning processes. For example it is possible that the drilling process affects an measuring process of the depth of the hole performed simultaneously.

4 CONCLUSIONS

The description regarding the process model and the uncertainty analysis which is based on it show:

- A large number of technical processes can be described with a uniform model.
- On the basis of the process models it is possible to develop a uniform understanding of the emergence and effects of uncertainties. Therefore comprehensive and detailed process models can be used as a basis for uncertainty analyses.
- The use of systematically developed and to a large extent complete process models for the uncertainty analysis makes it possible to assign uncertainties to certain process elements.
- On the basis of the represented process model, systematically developed and to a large extent complete check lists can be compiled as aids for the determination of uncertainties.
- A methodically justified classification of uncertainties on the basis of the developed process model is possible. Typical classes of uncertainties can be defined this way. Thus, the complexity of handling uncertainties is reduced. Furthermore, guidance for typical measures for the containment of corresponding uncertainties can be given according to the classes.
- A special advantage of the used process model is the fact that it covers product and process in a differentiating form.

In the following research work, methods for the process based uncertainty determination are to be developed, building upon the hitherto existing results. Check lists, typical examples of uncertainty emergence and typical solutions to the reduction of uncertainties should be made available. Furthermore, methods are to be developed for the identification of critical processes and process characteristics regarding uncertainties.
For complexity and the extent of uncertainty analyses, supporting CA-tools would be very helpful in the future.
A further important goal is also the porting and application of the process-based uncertainty analyses to product and process development processes.

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Contact: Dr.-Ing. Hermann Kloberdanz
Technische Universität Darmstadt
Product Development and Machine Elements
Magdalenenstrasse 4
64289, Darmstadt
Germany
Tel: Int. +49 6151 162255
Fax: Int. +49 6151 163355
E-mail: kloberdanz@pmd.tu-darmstadt.de
URL: www.pmd.tu-darmstadt.de

Hermann Kloberdanz is senior researcher at the institute “Product Development and Machine Elements” at Technische Universität Darmstadt. His main research fields are product development and design methodology, focusing on Robust Design – methodology.

Roland Engelhardt is research associate at the institute “Product Development and Machine Elements” at Technische Universität Darmstadt. His research is part of the CRC 805 financed by the German Research Foundation. He is working on the subproject “Development of Models, Methods and Instruments to Capture, Identify and Estimate Uncertainties in Technical Systems”.

Johannes Mathias is research associate at the institute “Product Development and Machine Elements” at Technische Universität Darmstadt. His research is placed in the CRC 805 and he is treating the subproject “Robust Design – methodology to design uncertainty optimal systems”.

Herbert Birkhofer is head of the institute “Product Development and Machine Elements” at Technische Universität Darmstadt. He was founding president of the international society "The Design Society". His main research fields, knowledge management in design, empirical design research and development of environmentally sound products.