Product Life Cycle Oriented Representation of Uncertainty

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Abstract. In this paper an innovative approach is presented, which enables modeling and exchanging information about the uncertainty of product properties along the product life cycle providing improvement for product development. A system which is called "COPE" (Collaborative Ontology-based Property Engineering System) is proposed, which uses the advantages of an ontology-based approach. The proposed system captures information about product properties and the circumstances as statistic of fuzzy information, and combines them with the product model, to provide information about the actual and possible future product life cycle processes and the future product properties to the stakeholders.

Keywords: Knowledge Flow, Product Data Standards, Uncertainty, Information model, Ontology.

1 Introduction

Uncertainty in the design process about future performance parameters is a major problem in the product development. The designer needs information about the conditions the product will face in its life for the safe and economic design of the product. The control of uncertainty, especially in load bearing systems, is addressed in the collaborative research center (CRC) 805 - Control of Uncertainty in Load-Carrying Systems in Mechanical Engineering - founded by the Deutsche Forschungsgemeinschaft (DFG). In [1] the following working hypothesis of the term uncertainty has been defined: "Uncertainty occurs when process properties of a system cannot be determined. Uncertainty can be described and can be quantified with known methods of risk analysis". The terms uncertainty, risk and reliability seem to have the same nature, although there are differences between them. Risk describes the probability of the occurrence and the severity of a certain event. With reliability the probability of a failure depending on the circumstances is described. Uncertainty describes the inability of an exact determination of process properties and the resulting effects. Therefore uncertainty can be described by properties and effects between those. Figure 1 depicts this model of uncertainty. Aim of this model is to combine different views on uncertainty from different fields of research regarding to load carrying systems. It was elaborated and compared to other models of uncertainty in [2]. An overview and a

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proposed classification of uncertainty is given in [17] and is discussed in our approach.

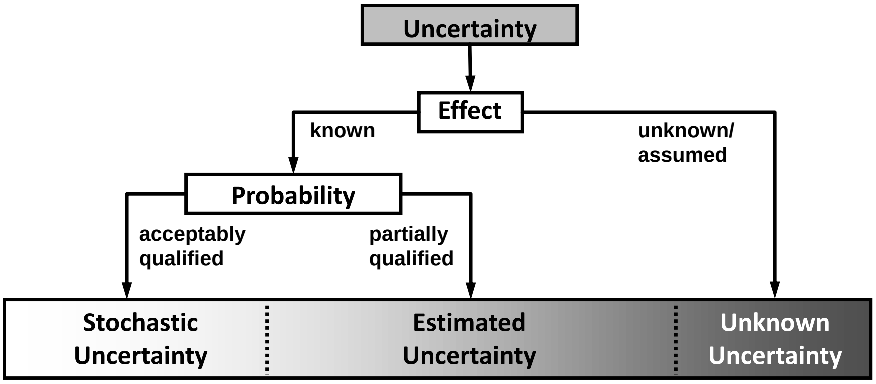

Fig. 1. Uncertainty model [2]

For the control of uncertainty and so the determination of process properties and their effects, information and its exchange along the product life cycle is necessary. The management of the uncertainty related information in the specific life cycle processes is fragmented to several subsystems like CAQ or usage monitoring or the collection of service and inspection data [3]. This issue leads to suboptimal designed products, higher costs or less safe products. To overcome this issue the engineer needs information about the properties of the real products. This information exchange between different stakeholders in the product life cycle brings up several challenges. Brunsmann et.al depict in [4] the general approach for the exploitation of product life cycle data in terms of development, manufacturing and usage. They show that this information is very valuable, and they describe several challenges which need to be addressed. They propose the use of lightweight ontologies. In [5] Brunsmann proposes such an ontology based approach. The uncertainty the applicability or transferability of the information is not part of these approaches. Unlike in geometric representations there is no common information model or standard for uncertainty related information. This information has high complexity. With the representation of uncertainty the processes and their circumstances are focused. The needed information is created during the product life cycle by different stakeholders. There must be a clear localization, definition and description of each property and the circumstances.

Nowadays the tools and standards in the field of PLM do not offer the possibility to clearly describe and identify uncertainty in different instances of product- and process-properties in the course of the product life. This issue is addressed in this paper. The representation of uncertainty, the need for collaboration, common definitions and standardization, demands a sophisticated information model. An approach of such a model is presented in this paper. It is an ontology based approach which is beneficial for the communication and the understanding along the product life cycle. To clearly identify properties and to create a structure among them different standards from the field of mechanical engineering are used to create taxonomies for product properties and processes. The resulting ontology is supplemented with an existing product referencing model and a representation of uncertain values.

1.1 Need for Action

As the authors presented before, the determination of future process properties is a success factor in the development of products. To render the possibility of such determination the use of information from the past is a possibility. Existing approaches do not address uncertainty with its full scope. This information must qualify the properties and describe the effects among them. Furthermore the applicability of this information is an issue. Therefore the effects and properties as well as the circumstances have to be described properly. To do so it is necessary to answer the four questions: "which", "where," "when" and "wherefrom". In the case of properties these are:

- Type of property (Definition) and kind of value (stochastic, tolerance,…).
- Location of the property in the product (diameter of hole …).
- Which state and process in the product life is described (new or worn out product).
- Wherefrom comes the information (measurements, worst case assumptions,…).

With this description of a property it becomes possible to describe properties in the product life cycle and to use this information for the prediction of product properties. The same questions in the case of effects these are:

- Type of effect representation (quantitative, qualitative).
- Where is source and sink of the effect (x effects y).
- In which process the effect occurs (forming effects rigidity).
- Wherefrom comes the information (general assumption, correlation …).

This information can be used for predictions with respect to is applicability. The applicability and the trustworthiness of the collected information depend on the processes and the circumstances in which they were collected, what makes the information complex. Based on this assumption four main requirements are resulting:

- There must be clear definition and description of the regarded element (Property/Effect).
- An unambiguous identification for the evaluation of contextual uncertainty is necessary. Therefore there must be a frame of reference to the geometric product representation.
- Definition and identification of process and the respective circumstances the information stems from.
- Description of the source and the character of the information.

There are existing approaches and standards for certain aspects of this issue but they are for each not capable to fulfill all these requirements. Therefore the authors present an ontology-based approach which extends the integrated product model to meet these requirements.

2 Collaborative Ontology-based Property Engineering System

The necessary information is first identified and classified to provide support for the evaluation of the information. Afterwards the exchange of existing information is discussed by means of information integration with the COPE approach (Collaborative Ontology-based Property Engineering System). This integration provides the necessary structure for the representation of uncertain properties and related information. Afterwards the methodic integration in the product life cycle is presented.

2.1 Identification and evaluation of uncertainty Information

For purpose identification and classification of uncertainty related information available standards were analyzed. A system for the collection of information about reliability along the product life cycle is described in the VDI 4010 - Reliability data systems- [6]. The advantage of this standard is the fact that uncertainty is a similar concept to reliability. In this standard reliability data systems are described in terms of general concepts, types and use of data, and the planning of reliability data systems. It provides information about the management and processing of information which affects development as well as usage processes. To do so, it focuses on the value contend of the property in terms of the kind of the data. It is distinguished between raw and derived data, meta-data, event data, and the provenance of the data. Reliability data systems are used to collect information about the operation conditions and the defect rates and causes of a regarded unit. In [17] a classification of uncertainty is proposed, which divides uncertainty into context uncertainty, data uncertainty, model uncertainty, and phenomenological uncertainty. According to this approach and the VDI 4010 analogous types of uncertainty information for load bearing systems can be identified. The identification and the structuring of the information are used to provide the basic information for an evaluation of the provenance and the trustworthiness of the regarded set of information. It is distinguished between:

- Context representing information and uncertainty representing information. The first type describes the properties context like product reference and process description. Uncertainty representing information is the description of a property or an effect.
- According to the amount of processing: Raw data and derived data. To evaluate the trustworthiness for a specific task the raw data is useful. Derived data is processed raw data in like e.g. standard deviation and correlation coefficients.
- According to the source: Process specific-, not process specific-, mixed- and general information. Process-specific information stems from the same process for which the information will be used. Not process specific information therefore represents estimations based on similar processes. Furthermore a combination of these two types can exist which is called mixed-information. Generic information describes only typical values of properties or general effects.

These types of information render the possibility to represent uncertainty in the product life cycle and to evaluate the appropriateness for a specific use of this information for the determination of future process properties.

2.2 Information integration

For our approach an ontology-based system is chosen. Ontology-based information models provide in this context several advantages against traditional relational or object oriented approaches. Ontologies are based on taxonomies in which the elements can be clearly defined. This is an advantage within a heterogenic field of application, as it is given in the product life cycle with design, manufacturing and usage. Furthermore ontologies are based on web technologies, which render the possibility of a distributed system and easy access to information. With the focus on uncertain properties, and uncertain relations, ontologies offer new possibilities to make statements on different levels of precision, based on the class hierarchy. For example: “forming influences material properties” as general/uncertain statement or “forming influences rigidity”, with rigidity being a subclass of the abstract class material properties as a definite statement.

Figure 2 depicts an overview over the ‘COPE’ (Collaborative Ontology-based Property Engineering System) approach with its major elements. COPE combines the three sub-lifecycles development, production and usage. According to the requirements it describes uncertainty as the uncertain property value and an uncertain relation, which describes the effect of the uncertain value. To describe the context of these two elements a process model and the product model is used. The property and process classification build the major part of the taxonomy of the ontology. The role of a certain uncertainty information element is described by its provenance. The management of these elements can be supported rules and the inference engine. The four major elements will be described in the course of this chapter.

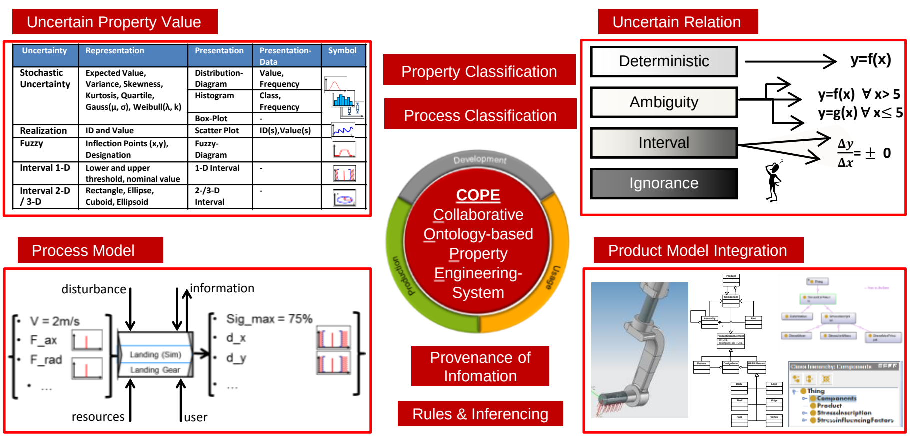

Fig. 2. Overview of COPE

Properties.

To communicate along the product life cycle it is necessary to use standardized terms and definitions for the representation of information about properties, and processes in the product life cycle or to give support to create these terms and definitions where they are missing. For a very general approach the NASA provides a basic ontology called 'qudt'[1]. It provides quantities, units and data types in an ontology. In the field of standardized properties there exists the standard DIN 4002 - Properties and their scopes for product data exchange – [7]. This standard is compatible to other important standards in this field like ISO 10303 -Product data representation and exchange- (STEP) [8]. In DIN 4002-100 a according online dictionary is called 'DINsml.net' [2] is defined which aims to provide standardized properties for the use for e-business applications, product catalogues, and product life cycle applications. The DINsml.net platform defines the properties in a hierarchical framework which provides not only the definition of a property. It provides also a frame of reference for the properties. The 'DINsml.net' platform is still a subject of ongoing standardization activities so there are some fields which are not covered sufficiently. This brings the need to define own properties, especially with very specialized products and their respective properties. Nevertheless the schema of DIN 4002 provides a sufficient background for this purpose. Using this standard as far as possible and to define additional properties where they are missing brings the needed flexibility. Table 1 depicts some attributes for properties.

Table 1. 'DINsml.net' Attributes of Properties [7]

Preferred name	Source of Definition	Value list	Preferred Symbol
Identification	Short name	Remark	Alt. Symbol
Abstract property	Synonym	Comment	Coverage
Definition	Unit	Type of Property	Property-Datatype

The formalized representation and presentation of uncertain values of properties is still a subject of ongoing research. With UncertML [9] an XML-based approach is made to describe the stochastic uncertainty of measurements and calculations in the field of geospatial data. The approach is focused on the representation of stochastic key indicators. The representation of uncertain values requires also well-defined terms. The UmcertML approach provides broad spectrum of stochastic key indicators each with a definition. In [10] the authors present an extended approach, which uses the definitions of UncertML for the stochastic key indicators. It supplements also fuzzy, intervals in one two and three dimensions and single values to cover the qualification range of the uncertainty model presented in the introduction. The presentation of stochastic values (e.g. in a histogram) is also part of the extension. This renders the possibility of an integrated representation of the value itself and its presentation, which serves basically for a visualization of uncertainty [11].

[1] www.qudt.org

[2] URL: www.dinsml.net

Uncertain Relations.

Variability of process- and product properties causes effects on other properties in the product life cycle. According to the used definition of uncertainty it is not sufficient to describe only the variability of a property. To understand the uncertainty the major effects of the variability have to be identified in the processes and represented in the information model. Due to different amount of knowledge this description has different types. The ontology based approach renders the possibility to create different types of relations with the ability to represent different stages of knowledge. In [14] the authors present an approach to use an ontology based model to represent uncertain relations like e.g. statistic correlations of product properties in combination with an ontology-based product model. A relation consists of source and sink of the relation and a description of their interdependency. Depending on the cardinality of source and sink, the types 1:1, 1:n, 1:M are supported. The two first types are common types, known from relational database management systems. The 1:M relation describes a special ontology-based relation. It describes relations to abstract property classes. The qualification of the relation has also four types. The deterministic type represents known physical laws and identified correlations. The function and its parameters are well known. An ambiguity relation describes that a property influences a property or a group of properties (e.g. temperature). The interval relation describes the quality of the relation.

Process-Model.

The processes of the product life cycle have to be described to give a context to the uncertainty. A process model for uncertainty is described in [12]. It is a graphical pen and paper method which describes processes in terms of uncertainty with their influences. A process is characterized and thereby also identified by:

- Name. The name of the process characterizes the type of process. (e.g. Drilling, Landing)
- Appliance. This describes a needed resource which is not consumed during the process (light aircraft, Piper PA-28).
- In- and output. Representing the transformation which is done by the process. Both consist of a list of properties (speed, load, angle).
- Influence factors. Describing properties which influence the process result. These influence factors are divided into disturbance, information, resources and user (temperature, energy, qualification).

This model serves as scheme for the process representation. It is supplemented with standardized terms in the ontology. In the field of manufacturing there is a classification of manufacturing processes given in the standard DIN 8580 - “Manufacturing processes - Terms and definitions, division”- [13]. This standard gives an overview over the broad spectrum of production processes, from primary shaping, forming, to assembly all important production processes in mechanical engineering are covered. This classification is used in our approach for the naming and of manufacturing process. The definition of a standardized name in the field of usage processes is not as well supported by standards as by manufacturing. The usage processes are highly dependent on the product. For each type of product there are different usage processes, which have to be defined. Our research focuses on load bearing systems in mechanical engineering. In this field there is no suitable standard nomenclature for usage processes known to the authors. The typical usage processes are anticipated in the product development, and could be defined here also.

Product Model integration.

This approach defines yet uncertainty and processes and uses as far as possible a standardized nomenclature. To identify a property unambiguously the respective localization on the product must be known. For example in a part there could be more than one diameter or more than one drilling processes. The ISO 10303- STEP standard provides a broadly used standard for product data exchange (ISO 10303) [8]. STEP aims to represent information from the whole product life cycle with the concept of the integrated product model [15]. A main filed of application is the geometric product representation. STEP also provides powerful versioning, managing of different views on a version which can be used as a background for a powerful management different information sources for uncertainty. This renders the possibility to describe the source of a set of information by a view. The representation of the product geometry in STEP can be realized by a Boundary Representation (BREP). This type of representation offers advantages for the annotation of additional information. . In [16] an approach for the semantic annotation of additional information to the product model is presented. In this approach the BREP (Boundary Representation) model of the product is used to annotate the topology. In this approach the topology of the product model is used to refer the information about the properties collected in the product life cycle to the product model. The topologic elements are used to annotate the uncertainty information to the geometric product model to identify the uncertainty unambiguously in the product life cycle.

2.3 Methodic integration

The presented information model renders the possibility to store and exchange uncertain product property data. In this chapter the methodic integration of this information into the product development process is described. This method is derived from the VDI 4010 which describes the usage and transferability of reliability data. This approach is extended for the use with the ontology-based information model. It is depicted in figure 3.In product planning and development there is only little information about the product property uncertainty. Estimations based on expert knowledge supported by methods like QFD or FMEA, are often the only available information sources to a specific problem. Due to the unknown product and process properties the product is designed with safety factors based on these estimations. The resulting safety factors may be improper and cause higher cost and suboptimal performance in the product life cycle. During the production of the product, information about the products properties is collected e.g. by statistical process control or quality assurance in different types and representations. In experiments and through usage monitoring the operation conditions of the product are available. The information from manufacturing and usage of the product is stored in the information model which is now valuable information for the redesign of the product with controlled uncertainty and appropriate safety factors. For the development of a variant of the product or a variation in the production process the information is also very valuable. It allows much more precise estimations of the uncertainty which has to be expected with the new product or processes.

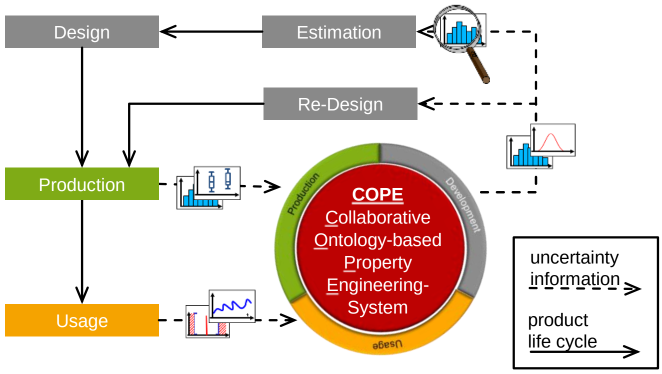

Fig. 3. Methodic integration

3 Conclusion

In this paper the issue of uncertainty in the product development is addressed. Uncertainty in this context is represented as the level of qualification of a certain property and the effects of its variability. To control uncertainty the integration of information from the whole product life cycle is necessary. Several challenges and requirements were described.

The presented approach enables modeling and exchanging information about the uncertainty in an ontology-based information model. The proposed system supports the capturing of this information in different levels of detail, to store information about the actual and possible future product life cycle processes and the future product properties to the stakeholders. For an unambiguous representation and exchange of uncertainty related information along the product life cycle semantic technology combined with available standards were considered. These standards provide a good foundation but have to be extended in some points. The methodic integration of this system, to use the given information appropriately is also presented. Herein the focus is on the applicability and transferability of the given information. This approach renders the possibility to improve product life cycle management for a more safe and economic design of existing and future products.

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