AN APPROACH TO THE PROPERTY-BASED PLANNING OF SIMULATIONS

Reitmeier, Jochen; Chahin, Abdo; Paetzold, Kristin
Universität der Bundeswehr München, Germany

Abstract

The requirements related to technical systems are very diverse. This ultimately leads to an increase in complexity in products and in development processes. Due to time and cost pressure, effective methods are necessary to focus on activities with real added value in terms of lean product development.

Continuous validation of product functionality must be ensured throughout the development process, this is done by means of simulations as far as possible. Simulation methods are well known and a variety of powerful tools is available. However, it is still an open issue, which simulations can be executed at what point in time to really support development processes. In addition, the coupling of the quality of input data and the quality of analytical results is not considered enough.

For this reason, a situation-specific and generally applicable approach to a property-oriented simulation planning is presented to detail and support steps of analysis. These will be essentially triggered or rejected based on the quality of required input data. Moreover, maturity estimations and decisions based thereon with respect to product modification and course of the process are also supported.

Keywords: Decision making, Design process, Product modelling, Quality evaluation, Simulation planning

Contact:
Jochen Reitmeier
Universität der Bundeswehr München
Institut für Technische Produktentwicklung
Germany
sijoreit@web.de

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1 INTRODUCTION

Today, essentially mechatronic products are developed to meet the manifold requirements concerning technical systems. In addition, the trend of decreasing product life cycles is forcing companies to continuously implement innovative ideas within a short time in high quality, yet affordable products. These aspects finally lead to an increasing complexity in products as well as development processes. Therefore, both simple and effective methods and tools for development processes are necessary in order to focus on activities with real added value in terms of lean product development.

1.1 Problem description and motivation

Continuous validation of product functionality must be ensured throughout the development process. The product's behaviour caused by the product's properties and by taking into account the specific usage and environmental conditions is the relevant measurement (Roozenburg and Eekels, 1995). A purposeful and early validation reduces the development risk as well as the need for (rather unnecessary and costly) iteration cycles. In this context, it is *particularly noted*:

- Today, property validation is done by means of simulations as far as possible. Simulation methods are well known and a variety of powerful tools is available. However, it is still an open issue, which simulations can be executed at what point in time to really support development processes.
- It is absolutely necessary to indicate simulation results concerning the used input data to prevent systematic errors and avoid implying a precision that does not exist. The satisfactory data quality depends on the current process step, analysis objective and raises with the course of the process. But, especially in the early development stages data and information are subject to uncertainty.
- In (mainly) virtual development processes, simulation results are an essential basis for product maturity estimations. Based on these, release processes or iteration cycles are triggered. This means that the quality of maturity estimations and the process is closely linked to the simulation quality.

1.2 Objective and comprehension of simulation planning

The preceding statements underline the need for a methodological support to targeted execute property validations. Therefore, the objective is to develop an efficient approach to simulation planning in order to support a process attendant validation of product properties. The key research question is, how this approach must be described and what aspects need to be considered.

Operational process models, that are assigned to the level of problem solving, are part of the phase respectively strategic process models of classical design methodology, e.g. VDI 2206 (2004). These are essentially characterized by a permanent change of synthesis and analysis steps. According to Weber (2005), development data can be fundamentally differentiated in characteristics (e.g. dimensions, material) and properties (e.g. mass). Therefore, a classification of product data is available, which already allows a reference to process steps. Within steps of synthesis (develop solutions), an increasing concretisation of the product is done by defining characteristics (cause). The respective validation of achieved properties (effect) is done within steps of analysis (analyse solutions).

The basic idea of simulation planning is to process product data in such way that they can be evaluated and used in the simulation context. Hereby, steps of analysis are described in more detail, based on the *following perspective* (Reitmeier, 2014):

- The requirements management and aspects concerning the Design for X (DfX) provide concrete target properties as reference criteria as well as the determination and prioritisation of test cases. This is assumed to be a previous respectively parallel process.
- The objective of property validations is depending on the process step and used simulation tool. Consequently, specific data requirements in terms of scope and accuracy are herewith associated, example chassis development (Heißing, 2011): in the early stages of development simplified models are used to analyse the kinematic behaviour, more accurate analysis using multi-body simulation take place when concrete material properties or load cases are available.
- Development processes are highly iterative. Hence, property validations often must be rescheduled and effects of modifications on other properties including validation needs must be identified.

- A detailed and completed simulation planning at the very beginning of a project is neither possible nor wise. Mechanisms are rather required to operationally trigger (situation-specific approach) simulations: a simulation is only useful if the necessary data are available in sufficient quality.

In this paper, five essential aspects are addressed that need to be considered, following Reitmeier (2014):

- An *efficient product modelling* must be used as the basis to control the multiple dependencies in complex products. This relates to the possibility to (quantified) identify efficient set screws (characteristics) to manipulate properties as well as the mutual dependencies of properties. That way it can be also identified which input data are required to validate a specific property and which validation needs arise due to dependent properties. This must be finally complemented by *process-relevant information* to enable a situation-specific approach.
- An adequate *quality evaluation of simulation results* is to provide, as these are only as good as the quality of the input data or the simulation model. If an anticipated analysis quality is available before execution, these may be rejected due to insufficient analysis quality and measures for their improvement can be identified. In addition, maturity estimations or decision-making processes concerning release mechanisms or iterations cycles are supported by more detailed analysis results.
- The *overall concept of a property-oriented simulation planning* should be used not only as an independent and global approach. It is rather intended to enable the integration of these approach into existing company-specific process models. This offers the possibility to use and complement the information flows described therein. Finally, this theoretical concept has to be *practical provided*, e.g. within workflows of a product data management system (PDM-system).

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2 STATE OF THE ART AND DEDUCTION FOR NEED OF ACTION

This chapter briefly describes the relevant state of the art and addresses respective need for action.

2.1 Product properties

Product properties are considered to be the most relevant aspect for the product user and thus constitute the guideline for development projects (Herfeld, 2007). There are different approaches concerning systematization and classification of properties: these are not always consistent, but have overlaps, see. Reitmeier (2014). The common intention is to characterize a technical system. However, none of these approaches provides a procedure how properties can be actually realized or validated.

As already noted in chapter 1.2, the classification of product data referred to the CPM approach by Weber (2005) provides a reference to processes. By using different terminology, *characteristic* (cause) and *property* (effect), the alternating and essential steps of development processes, synthesis and analysis, are emphasised. The PDD approach by Weber (2005) is built on the CPM approach and deals with the concrete course of development processes. Here, the difference between the desired and actual properties is the driving force. The execution of specific property validations can be linked to the number of specified characteristics and essentially supports a process attendant simulation planning. This also offers the possibility to clarify "What data/information are needed for a specific simulation?".

Several projects dealt with the CPM/PDD approach in the recent years and offer basic principles to control the dependencies within a product. Nevertheless, they only deal with specific development tasks or separate synthesis and analysis. Beside the question, when property validations can be performed efficiently, it remains open which and how much other properties are influenced, when the actual value of a property changes or characteristics are modified. Both is necessary to identify validation needs.

2.2 Determination and evaluation of the actual level of development

Virtual, computational property validations (Computer Aided Engineering, CAE) are classified as methods of analysis with respect to the problem solving procedure. According to Bossel (1994), available simulation methods can be essentially divided into two categories. These are applied at different stages in the development process depending on the objective of the analysis, whereat minimum data standards as well as the maximum gained findings are linked:

- *Parameter oriented modelling methods* (black-box-principle) analyse the technical system from a functional perspective. The system behaviour is focussed, the wirk structure plays a minor role.
- *Field theoretical modelling methods* (glass-box-principle) require concrete data concerning the wirk structure (material and geometry) in order to simulate and analyse the system structure.

The objective of the conceptual stage within mechatronic development processes is to identify the best possible solution. For this reason, more abstract models with respect to the concretization degree of required properties are preferred and black-box approaches that represent the system behaviour (solution-neutral) are used (Paetzold and Reitmeier, 2010). In the following domain-specific stage, the work focuses on the determination and refinement of characteristics with respect to the required and concretized target properties. Because of the known wirk structure, glass-box approaches are used now. Structural thinking in the participating domains of mechatronic product development is differently: therefore, property validations are locally executed, within the departments. In the system integration phase it is advantageous to use black-box approaches, the essential characteristics or properties of each subsystem are identified and serve as input variables for analyses of the overall system behaviour. Glass-box approaches can also be used to link models from different disciplines, but, this is very complex and requires a high computing effort (Paetzold and Reitmeier, 2010).

According to the PDD approach, early and late phases of product development process can be distinguished based on the number of specified characteristics. The more and detailed characteristics are available, the more specific and more detailed analyses are possible. This means that the same properties are analysed with different tools in early and late phases.

X-in-the-loop (XiL) methods are used when mechatronic development does not want to rely only on pure virtual validations due to the model simplifications (Roddeck, 2012). XiL is a combination of real and virtual test, where the "X" is a substitute for the specific application. In this context, the domain-specific components must be reduced to their main characteristics and properties.

CAD and CAE data have different formats and are stored in different systems. Available approaches to improve the link of CAD and CAE mainly focus on interface solutions (IGES, STEP, CORBA) or data exchange (e.g. Anderl et al., 2009). Approaches focussing on product models (e.g. Herfeld, 2007), provide only stand-alone solutions, since they focus on specific issues. Many property validations are also executed in parallel due to aspects of time, although dependencies often exist between them. There is also no general solution for this purpose. In addition, the coupling of the quality of input data and the quality of analytical results is not considered enough.

According to Helling (2006), the product maturity is the relation of the actual value of a property and its target value. In predominantly virtual development processes, the quality of simulation results is subsequently reflected in the quality of maturity estimations. This results in decisions regarding release processes or iteration cycles. The latter usually lead to new analysis needs and must be considered in a simulation planning to targeted support these activities respectively resulting aspects must be picked up.

2.3 Data quality

Many data and information (both terms are often synonymously used in practice, cf. Wang and Strong, 1996) arise in the course of development. Therefore, especially in the early stages of a development project, many assumptions have to be made or worked with uncertain data. Consequently, uncertainty considerations became increasingly important in the recent years, so that a wide variety of approaches are available. These are not universal, since they are based on specific views or objectives. They deal either with classification and detection and/or mathematical description and calculation of uncertainties (see Kreye et al., 2011); mentioned aspects initially occur in Derichs (1997) or Wang and Strong (1996).

The degree of data/information uncertainty is often expressed by evaluations of data/information quality. The term "data quality" is nearly always interpreted as a *multi-dimensional construct*. According to Würthele (2003), data quality is a multi-dimensional measure of the suitability of data to meet the present purpose; this suitability may change over time as needs change. This view emphasises the relation to a specific point in time and can be interpreted as an indirect connection to a specific process step or the prevailing context of use. This also reflects the objective of a simulation

planning, as a support should be offered in a concrete decision situation concerning the execution of an analysis.
For the characterisation and evaluation of data quality, various approaches exist, each focusses on a specific context of use. The quality assessment by Wang and Strong (1996) has to be mentioned as the fundamental and most-quoted approach to describe and assess information quality (Treiblmaier, 2006). This approach assigns 15 quality attributes (each is representing a specific aspect) to four quality dimensions. These were determined in a two-stage empirical survey followed by a two-stage analysis. Each of these dimensions is a critical success factor for the functioning of an information system and serves as a quality assessment of an information product.
There is no method available to assess the quality of analysis results, especially not in the property-oriented context. Although some approaches consider the model quality, there is no concrete evaluation of the used input data respectively only the timeliness of data is considered (e.g. Helling, 2006).

2.4 Development situation

Due to changing boundary conditions, simulation planning must be a situation-specific approach, since data requirements, availability and quality is dependent on process step and objective. In addition, requirements, as boundary conditions for simulations, can change as well as necessary property validations arise after the concretization of a solution (e.g. mounting aspects).
Following the perspective of Ponn (2007), a development situation represents a specific point in the development process that can be described by the status of the product to be developed and the development process, as well as factors influencing product and process. There are several concepts of different fields available to describe situations; the existing approaches are based on different objectives, situation types, conditions or categorisations (see e.g. Ponn, 2007). Consequently, there is no universal description of a situation or particular development situation. Situations are mostly described and analysed by *factors* that refer to the relevant situational context.
There is no approach which may directly support a planning of simulations. Either the concepts are too universal or focus on (not analyse) specific perspectives. According to Meißner et al. (2005), indications are also missing how such analyses can be incorporated into a process support. Therefore, process-relevant aspects for simulations have to be identified and made available in the process.

3 ESSENTIEL ELEMENTS OF AN APPROACH TO SIMULATION PLANNING

In the following, the essential and closely interlinked elements of a property-oriented simulation planning (chapter 4) are briefly shown.

3.1 Data model based on characteristics and properties

There is a huge variety of dependencies as well as effect chains between characteristics and properties in complex products, which have to be adequately (quantifiable) represented. However, simulation planning always means to structure, organize and analyse data and information flows with respect to the product in order to control virtual property validations. Accordingly, in this chapter, a data model is shown as a basis, which allows to represent the product related dependencies and to integrate required process-relevant aspects and information.

3.1.1 Basic structure of the House of CPM

Figure 1 shows the *House of CPM* as the basically used product model for simulation planning.

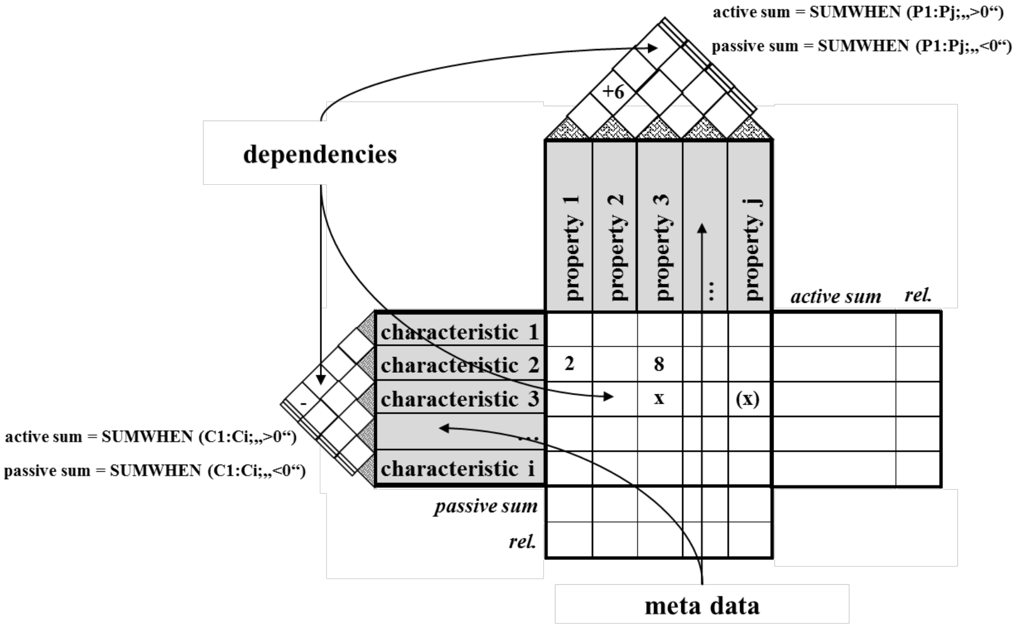

Figure 1. House of CPM, Reitmeier (2014)

Design Structure Matrices (DSM), Domain Mapping Matrices (DMM) or Multiple-Domain Matrices (MDM) are often used to represent or map elements of a technical system, processes, documents or people in a structured way (Lindemann et al., 2009). The House of Quality which is used within the Quality Function Deployment (QFD) method is a matrix based representation of dependencies as well (Akao, 1992). Using DMM, customer requirements are applied in rows and technical product requirements in columns to underline question "WHAT does the customer need and HOW can this be achieved?". The relations can be weighted. Theas means in the context of this work, which characteristics (HOW) have to be determined to achieve/influence properties (WHAT). Technical product requirements are weighted linked in the roof of the House of Quality. This means the transferred relationship between product properties, which can also be used for the dependencies between characteristics.

It is intended to illustrate the fundamental dependencies between characteristics and properties. The detailed illustration of physical relationships would lead too far as a clear quantification can be very or quite too complex. Extensions by adding columns and rows as well as selections on characteristic as well as on property level for different points of view (e.g. production) are smoothly possible. The data model can be set up for specific validations as well as individual components or an entire system.

3.1.2 Filling and analysis of the House of CPM

There are *four basic rules* to fill the matrices in the House of CPM:

- An empty box indicates that the relationship is still not known or rated
- A value of "0" indicates that there is no correlation
- An assumption concerning a relationship is to set in brackets
- Weights of relationships are set within the interval [0; 10]. This is recommended, as an 11-step scale has proved to be feasible and sufficiently differentiated with respect to the cost-utility analysis (of course other scales are legitimate). The higher the value, the higher the relationship or influence.

The filling of the characteristic-property-matrix is carried out from top to bottom. The influence of a characteristic on a property is either to identify purely qualitatively by an "x" or quantitatively by a corresponding weighting. *Filling* of the characteristic-matrix is done from top to bottom, the filling of the property-matrix from left to right:

- A "+" shows that a characteristic influences another, a "-" that the considered characteristic is affected by another one (each with or without weighting). If two characteristics have an undirected relationship, the prefix is to omit. This form of representation ensures a faster filling and avoids a high swelling of the data model in contrast to the filling of DSMs instead of the roof matrixes.

- The same scheme is applied in linking the property-property relationships, so that indifferent, complementary or competitive relationships become apparent. Such details result from the requirements management or can alternatively/additionally deposited in the form of metadata.
- A “!” underlines contradictory/mutually exclusive property relations that cannot be solved by the requirements management or are identified by steps of analysis, following Köhler (2009). This also applies to construction-related restrictions concerning relationships between characteristic.

As shown in Figure 1, the calculation of active and passive sum is contemplated to clarify whether an element is dominant (active) or rather influenced (passive), following Lindemann et al. (2009): a comparison of individual elements is done by means of activity (ratio of active to passive sum) or passive (ratio from passive to active sum). This can also be used to determine how much an element is networked and involved in changes in the system. Using criticality, as the product from active and passive sum, highly active and passive cross-linked (i.e. indifferent) elements are identified which shows their sensitivity to changes. The higher the criticality of an element, the more critical it is for the system. Activity and passivity must be determined for the DMM. The criticality can be also determined for the DSMs as similar matrix elements are opposed.

The extent of influence of modifications of characteristics/properties on other characteristics/properties can be identified by means of previous mentioned *analysis*. This gives an indication which changes lead to analysis needs and respective analysis can be directly considered or initiated. Accordingly, the passivity has to be interpreted inverted. Passive properties are more sensitive to changes in the system, which is at least an indication for the number or timing of respective analysis. At least, the data model finally offers the potential to identify efficient set screws to optimise the system within synthesis.

Modern 3D CAD systems provide the functionality of a parametric modelling. The presented data model can support this modelling on characteristic level by representing respective relationships, otherwise the parametric can be used to (partially) automatically fill the House of CPM. The detailing and mechatronic extension of the CPM concept (Reitmeier, 2014) also supports the processing of the House of CPM.

3.1.3 Inclusion of process-relevant information

The House of CPM must be supplemented by process-relevant information to be used as a basis for a situational simulation planning, so that specific decision situations are supported.

As mentioned in chapter 2.4, situations are mostly characterized by contextual factors. Therefore, based on a literature review, experience from student and industrial projects as well as the present task, 21 contextual factors were defined with close reference to Reitmeier and Patzold (2013). For a detailed explanation of each contextual factors, their origin and benefits, see Reitmeier (2014).

property: break distance			
revision status:	10.03.2014	*responsible person:*	Mr. Sop Njindam
actual value:	35,5m	*quality:*	not rated
release status:	in progress	*huge effect on:*	driving safety
target value:	< 35,0m	*mainly influenced by:*	mass of car

Figure 2. Exemplary data profile „property“, (Reitmeier 2014)

The contextual factors are included in *data profiles* for characteristics, properties and property validations (Figure 2) that are linked with the House of CPM to characterize them using appropriate metadata. This supports a fast assessment of the present situation. Furthermore, such profiles offer the possibility to add notes, such as additional possible property validations with the same simulation model or important influences of characteristics or properties on other product properties that have to be considered. This can not only assist in the planning of subsequent and necessary property validations but also concerning optimisation cycles.

3.2 Method to evaluate the data quality in the context of simulations

The basic idea is to assess needed input parameters concerning their data qualities and to (mathematically) aggregate the quality levels with respect to the relevance of the parameter and the quality of the simulation model to an overall value (Reitmeier and Paetzold, 2011). This represents the achievable result quality as the basis to reject or initiate simulations and to detail maturity estimations.

3.2.1 Data quality attributes in the simulation context

It was mentioned in chapter 2.3 that data quality is regarded as a multidimensional construct and mostly described by quality attributes in more detail. Based on the very detailed work by Wang and Strong (1996) and the dynamic approach of Derichs (1996), *9 quality attributes* assigned to *2 dimensions* of quality were identified and are considered to be relevant in the simulation context. The latter explicitly emphasizes, besides content uncertainty (e.g. shaft diameter between 50mm and 100mm), the contextual uncertainty (criteria: frequency of change, change time, change amount, reason for change) in order to incorporate dynamic aspects in uncertainty considerations. This is also reasonable in the simulation context, as property validations must always be oriented to the real course of development. Consequently, the attribute "potential of change" (of data/information) is established. The defined quality attributes will be targeted used in the evaluation method (Table 1), for a more detailed explanation or justification for their selection see Reitmeier (2014). Data quality is interpreted as a context factor which has to be evaluated situational and is included in the meta-information outlined in chapter 3.1.3.

Table 1. Quality attributes in the simulation context

<table>
<tr><th colspan="2">quality attributes</th><th>context of use</th></tr>
<tr><td rowspan="3">intrinsic dimension</td><td>believability</td><td rowspan="5">evaluate the data quality of input parameters</td></tr>
<tr><td>accuracy</td></tr>
<tr><td>objectivity</td></tr>
<tr><td rowspan="6">contextual dimension</td><td>timeliness</td></tr>
<tr><td>potential of change</td></tr>
<tr><td>value-added</td><td rowspan="2">identify required data and weight input parameters</td></tr>
<tr><td>relevancy</td></tr>
<tr><td>completeness</td><td rowspan="2">compare required and available data</td></tr>
<tr><td>appropriate amount of data</td></tr>
</table>

3.2.2 Procedure to evaluate the situation-specific data quality

A simple and reasonable method must be offered to enable an efficient evaluation of property validations in the daily business. In this regard, an evaluation of each criterion is certainly not appropriate (e.g. hundreds/thousands of characteristics as input parameters for the strength analysis of a complex component). Therefore, an aggregation of the criteria within each dimension is proposed so that their effect is not lost, however, an evaluation considering all single criteria is targeted and simplified facilitated. This is also reasonable due to the fact that the individual criteria of a dimension are not necessarily independent of each other (e.g. objectivity influences credibility). The two dimensions themselves, however, are considered to be independent as they consider different aspects in the present context of use.

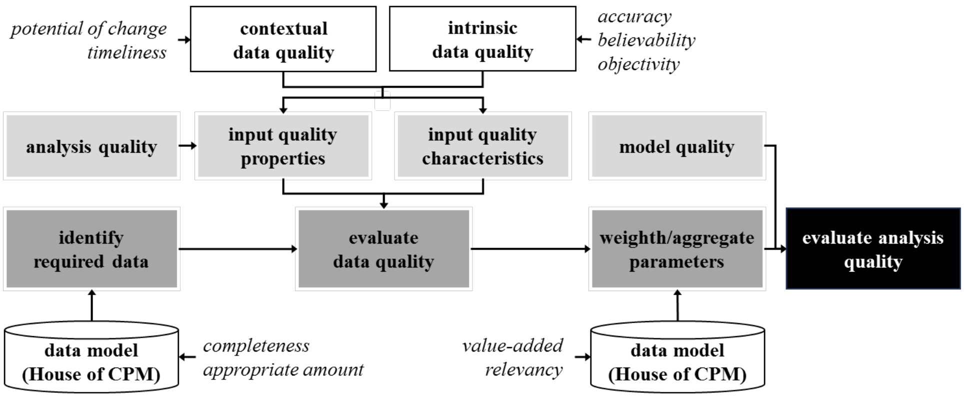

Figure 3. Evaluation of the result quality of property validations, Reitmeier (2014)

The *calculation of the result quality* is shown in Figure 3. The detailed calculation is described in Reitmeier (2014), the basic calculations are performed by addition and multiplication as follows:

- The required data for steps of analysis can be identified by the House of CPM.
- Characteristics will be evaluated concerning their intrinsic and contextual data quality. Both aspects can be weighted, appropriate weighting factors shall be defined by the users of the method.
- The quality evaluation of a property must be used when these is the result of a previous analysis. Otherwise, the quality of a property must be determined analogous to the quality of a characteristic.
- The qualities of the input parameters will be weighted regarding their effect, which can be identified by the House of CPM: the respective impact of each parameter is the quotient of its absolute relevance concerning the focused property and the sum of the relevance of all input parameters.
- The determined data qualities are now aggregated to a first analysis quality.
- These will be finally charged with a factor to consider the quality of the simulation model used (e.g. level of abstraction). This is according to Weber (2007) comparable to a confidence factor ([0;1]), which is rather low in early stages of the development process due to simple analysis and assumed parameters and high in later phases due to elaborated/verified models and accurate analytical methods. Model quality shall be determined by the user of the evaluation scheme.

The data quality is rated in the interval [0;10]. This is advantageous as an already known scale is used (cf. chapter 3.1), qualitative aspects are quantifiable and finally it can be easily converted into percentage points to point out quality lacks. Therefore, it is recommended to use percentages (point rating/10) when calculation the concrete quality value. An evaluation is done by participating construction or simulation engineers. The calculated analysis quality can also be supplemented by visualization aids (e.g. traffic light scheme) or recommendations for action.

The proposed evaluation method allows an *appropriate evaluation* of the achievable analysis quality due to the following aspects:

- The mathematical calculation can be easily processed by means of specific templates (including check boxes) and e.g. linked to the process step of a concrete analysis in a PDM system.
- Considering a simple strength analysis of a very detailed component in the domain-specific design, lot of characteristics have to be evaluated. Here, a simplification can be made as well: it is possible to consider and rate the entire CAD geometry by a single quality value and/or pick out and individually rate specific parameters (e.g. choice of material).
- Quality dimensions as well as criteria are easily interchangeable and, therefore, adaptable to company-specific directives; the basic scheme remains unaffected.

4 PROPERTY ORIENTED SIMULATION PLANNING – OVERALL CONCEPT

The basic concept of a property-oriented simulation planning is shown in Figure 4. There are essentially two decision situations, which need to be considered separately, following Reitmeier and Paetzold (2013): evaluation of the usefulness of a validation (D1) and planning of further process steps (D2).

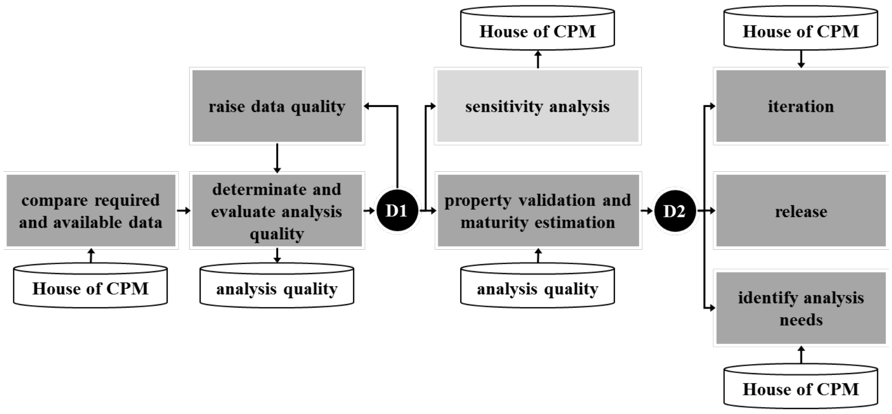

Figure 4. Situation-specific simulation planning, Reitmeier (2014)

The support and explicit consideration of the *first decision situation* is the focus of the presented work. The required input data (characteristics/properties) are identified by the House of CPM. If these are not available or released, responsible persons can be identified and contacted directly by the data profiles. The anticipated analysis quality is subsequently determined by the calculation method presented in chapter 3.3. If these is considered to be satisfactory, the property validation will be executed, otherwise this should be rejected first. In the case of essential quality lacks that become transparent by their weighted effect, the data profiles are again useful to contact data authors to eliminate these lacks. In addition, resource-related information (man hours/computer time) are deposited to support the project management regarding actual feasibility and lack of resources.

It is recommended to execute *sensitivity analyses in parallel* (especially for validations of new (sub-) systems and new validation methods), since assumptions of relations between input and output parameters can be confirmed or rejected. In addition, altered parameter relations can arise from considerably modified simulation models. Corresponding findings complete or update the House of CPM as well as the quality evaluation of the actual simulation result.

In the *second decision situation*, maturity estimations are supported and detailed by a kind of uncertainty factor concerning simulation results. The maturity management triggers iteration cycles or release processes. In the first case, the House of CPM or executed sensitivity analysis can provide valuable information concerning efficient set screws to optimise the solution: characteristics can be modified directly, properties can itemised on characteristic level. It is important to plan further property validations for the second case. If changes with respect to prior development levels concerning the analysed property are identified, it is to check which other properties are affected. If modifications of characteristics to optimise the just analysed property are determined, it must be also checked if this affects other properties. Certainly, property validations should only be scheduled, if the identified impacts exceed a certain level, which can be identified by the House of CPM. This must be determined in each case.

5 SUMMARY AND OUTLOOK

Due to the growing complexity in products and processes, effective methods are needed to focus on value-adding activities. For this reason, a situation-specific approach to a property-oriented simulation planning was developed to detail and support steps of analysis within virtual development processes. These will be triggered or rejected based on the quality of required input data. It is also possible to identify further analysis needs concerning changed properties or modifications of characteristics.

The presented approach is generally applicable and can be easily integrated into company-specific process models respectively adapted to company-specific circumstances. Although uncertainties are included in subjective quality evaluations and the (not yet) exactly determinable relations of input and output parameters, the shown evaluation method is promising to make a valuable contribution to a more sensible execution and evaluation of virtual property validations.

The next step is the validation of the proposed approach by considering the development of a new rotary engine, which offers the possibility to focus on a specific component as well as the whole (technically complex) system. Another aspect is to trigger variant-related analyses based on the matrix-oriented product description. At least, the prototypical implementation of the data model in a commercial PDM system is also promising (see Kößler et al., 2014) to practically integrate a simulation planning into workflow functionalities and will be expedited.

REFERENCES

Akao, Y (1992) QFD – Quality Function Deployment. Landsberg: Verlag Moderne Industrie.

Anderl, R.; Malzacher, J. (2009) SimPDM - Simulationsdatenmanagement: Standard nach Maß. In: CAD CAM, 2009 (1-2) pp. 38-41. ISSN 0723-1164.

Bossel, H. (1994) Modellbildung und Simulation. 2. Auflage. Braunschweig: Vieweg Verlag.

Derichs, T. (1997) Informationsmanagement im Simultaneous Engineering - Systematische Nutzung unsicherer Informationen zur Verkürzung der Produktentwicklungszeiten. Aachen: Shaker Verlag.

Heißing, B. (2011) Ersoy, M.; Gies, S.: Fahrwerkhandbuch. Wiesbaden: Vieweg und Teubner Verlag.

Helling, H. (2006) Konzept eines integrierten Produkt- und Prozessmodells zur effizienten Steuerung der Entwicklungsreife am Beispiel der Automobilentwicklung. Dissertation, TU München

Herfeld, U. (2007) Matrix-basierte Verknüpfung von Komponenten und Funktionen zur Integration von Konstruktion und numerischer Simulation. München: Dr. Hut, Produktentwicklung München, Band 70

Köhler, C. (2009) Technische Produktänderungen – Analyse und Beurteilung von Lösungsmöglichkeiten auf Basis einer Erweiterung des CPM/PDD-Ansatzes, Universität des Saarlandes, Schriftenreihe Produktionstechnik; Bd. 45. Zugl.: Saarbrücken, Univ., Diss.

Kößler, J.; Reitmeier, J.; Paetzold, K. (2014) Umsetzung einer eigenschaftsbasierten Simulationsplanung in einem PDM-System. EEE (Entwerfen Entwickeln Erleben) Konferenz 2014, 26./27. Juni 2014, Dresden.

Kreye, M. E.; Goh, Y. M.; Newnes, L. N. (2011) Manifestation of uncertainty – a classification. In: Proceedings of the 18th International Conference on Engineering Design. Copenhagen, Denmark.

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

Meißner, M.; Gericke, K.; Gries, B. (2005) Eine adaptive Produktentwicklungsmethodik als Beitrag zur Prozessgestaltung in der Produktentwicklung. In: H. Meerkamm (Hrsg.): Design for X. Neukirchen.

Paetzold, K.; Reitmeier, J. (2010) Approaches for process attendant property validation of products, 1st International Conference on Modelling and Management of Engineering Processes MMEP 2010, Cambridge.

Ponn, J. (2007) Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte. München: Dr. Hut.

Reitmeier, J.; Paetzold, K. (2011) Evaluation of data quality in the context of continuous product validation throughout the development process. In: Proceedings of the 18th International Conference on Engineering Design. Copenhagen, Denmark.

Reitmeier, J.; Paetzold, K. (2013) Process-integrated analysis of the development situation for an efficient simulation planning. In: Proceedings of the 19th International Conference on Engineering Design, Seoul, Korea.

Reitmeier, J. (2014) Eigenschaftsorientierte Simulationsplanung - Ein Beitrag zur effizienten virtuellen Absicherung der Produktfunktionalität, accepted thesis, Universität der Bundeswehr München

Roddeck, W. (2012) Einführung in die Mechatronik, Wiesbaden: Vieweg und Teubner, 4.Auflage.

Roozenburg, N.F.M.; Eekels, J. (1995) Product Design: Fundamentals and Methods. Chichester: Wiley & Sons.

Treiblmaier, H. (2006) Datenqualität und individualisierte Kommunikation. Wiesbaden: Deutscher Universitäts-Verlag.

VDI-Richtlinie 2206 (2004) Entwicklungsmethodik für mechatronische Systeme. Düsseldorf: Verein Deutscher Ingenieure (VDI).

Wang, R. Y.; Strong, D. M. (1996) Beyond Accuracy "What Data Quality means to Data Consumers", Journal of Management Information Systems, 12(4): pages 5-33.

Weber, C. (2005) CPM/PDD - An extended theoretical approach to modeling products and product development processes. In: Proceedings of the 2nd German-Israeli Symposium on advances in methods and systems for development of product and processes. TU Berlin / Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK), 07.-08. Juli 2005, p.159-179, Stuttgart: Fraunhofer-IRB-Verlag.

Weber, C. (2007) Looking at "DFX" and "Product Maturity" from the Perspective of a New Approach to Modelling Products and Product Development Processes. In: Proceedings of the 17th CIRP Design Conference.

Würthele, V.G. (2003) Datenqualitätsmetrik für Informationsprozesse. Dissertation, Lehrstuhl für Produktentwicklung, ETH Zürich.

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