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THE PRODUCT'S DEGREE OF MATURITY AS A MEASUREMENT FOR THE EFFICIENCY OF DESIGN ITERATIONS

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ABSTRACT
In this contribution a framework for evaluating design iterations and for assessing the effects of design iterations on the product's degree of maturity is introduced. Thereby, the product's degree of maturity is understood as being based on the products behavior since it is seen as the relevant measurement for the fulfillment of customers' requirements. Therefore, a distinction of the terms "function", "characteristics", "properties" and "behavior" is given and the product's behavior is described based on its characteristics and properties. Furthermore a differentiation between the terms "progress of the development process" and "product's degree of maturity" and a definition for these terms will be given. In addition, some fundamental challenges for evaluating the product's degree of maturity are depicted. An important connection between design iterations and the product's degree of maturity is drawn. Based on this, a framework for evaluating the effects of design iterations on the product's degree of maturity is introduced. Finally, a specific value is purposed for the appropriate measurement and evaluation of the efficiency of design iterations.

Keywords: product's degree of maturity, properties, iterations, efficiency of design iterations

1 INTRODUCTION
Design iterations in engineering design are common and appear almost every day. Hence, it is essential to distinguish advantageous iterations from unnecessary iterations. Iterations can be seen as an approximation, in which the developer approaches iteratively towards the optimal solution, because the solution often cannot be found in one step. Such iterations are necessary for engineering design and should be supported. But design iterations can mean also a jumping back in the development process and run through the process again. Triggers of those iterations are for example changes in the information basis, unclear requirements in the beginning of the process or late completion of the data basis [1], [2], [3]. A possibility to evaluate the advantage of those iterations is to focus on the product's degree of maturity: This measurement allows evaluating the effects of conducted design iterations and thus their influences on the product.
Conducting design iteration always means a change of the product's configuration during being developed. Frequently, those changes require or activate further product changes which can generate chain reactions. Therefore it is essential to consider all impacts of each conducted change. In [4] an approach for a change impact analysis based on the CPM/PDD-approach according to Weber is shown. An advanced variation of this approach based on the House of Quality can be used to evaluate the effects of design iterations on the degree of maturity of the whole product.
Hence, the aim of this contribution is to introduce a framework, which helps to evaluate design iterations by assessing their effects on the product's degree of maturity. In this contribution the fulfillment of the behavior required by the customer is seen as relevant measurement for the product's degree of maturity, because customers will be up to pay for the product only if the product's overall-behavior will meet their requirements. Furthermore, a specific value for assessing the efficiency of design iterations shall be introduced. To comprehend the product's degree of maturity, it is necessary to introduce a disambiguation and distinction between the terms "function", "characteristics", "properties" and "behavior". In the beginning some fundamentals for the evaluation of the product's degree of maturity are demonstrated, afterwards the framework for evaluating the effects of design iterations is introduced and then the specific value for the efficiency of iterations is proposed.

2 FUNCTION, CHARACTERISTICS, PROPERTIES AND BEHAVIOR

To safeguard a product based on its behavior, first there is to develop an appropriate method to depict the product's behavior. For this purpose and to avoid confusion there is to establish a clear disambiguation between the terms "function", "characteristics", "properties" and "behavior":

Within this contribution, the term "function" is comprehended as the technical system's sense, aim or task [5], [6]. If the system's function is not fulfilled, the system is more or less useless. The fulfilling of the system's function is the cause for the creation of a technical system and explains the technical system's effect [7]. Hence, the function establishes the relationship between input and output quantities of a technical system. With this understanding, defining the function of a technical system means a characterization of the technical system, which is neutral to any possible solution.

In this contribution, "characteristics" and "properties" of a product are understood analogue to the CPM/PDD-framework by Weber [8]: Characteristics are the "set screws", which can developers use to describe the product, to configure and to influence the product. Hence characteristics are specifications regarding structure, material and shape. Analogue to [9], characteristics can be divided in the two different groups of „physio-chemical form" (material) and „geometrical form" (geometry & structure).

Properties are understood analogue to [8]: The properties of a product cannot be defined directly, they result from the configuration of characteristics. Properties are measurable and quantifiable properties (like weight, stiffness, cost…) as well as merely qualitative assessable properties (like security, producibility, environmental friendliness, aspects regarding aesthetics…). Again, as shown in [9], properties can be divided in the two classes of „intensive properties" and „extensive properties". "Intensive properties" are specific properties (e.g. density, specific weight, specific stiffness…) and are a result from chosen material. Hence, they result from the design of the "physio-chemical form". In combination with the "geometrical form", the "intensive properties" define the "extensive properties" of a product: For example with the definition "steel" as material (physio-chemical form), there comes along the density of 7,85 g/cm³ (intensive property). With these "intensive properties" and the design of the "geometrical form", which is in this example finally the definition of the volume, the weight of the device can be determined. With this relation it gets possible to determine the so called "product's properties profile" by conducting analyses based on defined characteristics.

Within this contribution, the term "behavior" specifies the system's interaction with its environment. Thus, the "behavior" answers the question for the modality, in which the technical system fulfils its required function. Hence, the product's behavior is finally a specification of the function: The system's behavior implies not only its function, but even the way this function is to be fulfilled. Hence, contrary to the description of the function, the behavior of a technical system is not solution-neutral. When looking at the behavior of a technical system, neither the modality of realizing the system's function, nor the several components of the system are important. The system is seen holistic and its action respectively its influence on the environment is evaluated. Due to the fact that boundary conditions of later product application have an extensive influence on the product itself and its behavior, they are to be regarded during product development beyond doubt. To sum up, the behavior of a product can be considered as an outcome of the implemented profile of properties and of the influence of the so called "mode of conditions and use" (figure 1).

By using the terms and definitions as shown above, it is obvious, that from the profile of implemented product properties has to result such behavior, that - on examination of the given mode of condition and use - the required function will be fulfilled. The description of the technical system's behavior based on characteristics ("physio-chemical form" and "geometrical form") and its consequential emerging properties is shown in figure 1. For multidisciplinary products, it is necessary to expand this description of the product's behavior: For this purpose there are introduced the so called interdisciplinary machine elements. These are similar to the solution patterns in the CPM/PDD-framework by Weber [8]: For a given mode of condition and use, any machine element has a known profile of properties. While the discipline of mechanical engineering is using machine elements as bearings, screws or locking rings, the discipline of electrical engineering is using inductors, diodes or condensers. The development in the discipline of software engineering can (simplified) bee seen as connecting known functions in that way, that the resulting behavior copes with the requirements. Hence, in a simplified way, electronic devices can be regarded as machine elements of the discipline of electrical engineering, while functions (from function libraries) can be seen as machine elements of the discipline of software engineering. Common to all these domains is the connection of known solution patterns (thus the machine elements) in an appropriate way to reach the required function.

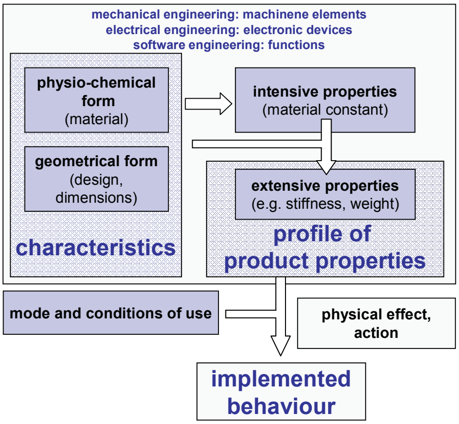

Figure 1: Description of products behavior based on its characteristics and properties

3 HOLISTIC SAFEGUARDING IN THE DOMAIN OF PRODUCT DEVELOPMENT

In addition to the customer's requirements there is a set of further properties to be regarded during the product development process, e.g. resulting from different phases of product's life. Those can be compatibility for manufacture, machining, assembly or transport. When safeguarding the product's degree of maturity, these varied aspects are to be considered, whose informational value and relevance vary dependent on the actual progress of development process. Furthermore, there are many requirements in connection with the holistic safeguarding of the product's degree of maturity, and different aspects as choice of indicators, the distinction between the terms "progress of the development process" and "product's degree of maturity" as well as the introduced way to describe products behavior are to mention. The following sections will have a closer look on these aspects.

3.1 Dealing with indicators

Indicators can be completed milestones, solved problems, amount of accomplished release-procedures, consumed time or caused costs. As requirements for those indicators are to mention for example their clear definition, consistency, quantifiability, simply measurability, possible weighting, comparability, fast conductible analysis and their independency from other indicators. By choosing indicators by using fix guidelines it gets possible to achieve an objective statement and arbitrariness can be eliminated. It is necessary to have a closer look at handling over-achieved indicators, thus indicators, which exceed their scheduled target: If an amount of work is fulfilled earlier as expected, or an achieved value exceeds the reference value (e. g. less weight than postulated), a specific value of more than 100% can be the result. To provide a possible compensation of under-achieved indicators by those over-achieved indicators, it is absolute necessary to reset these overachieved indicators to the value of 100%. By comparing the actual value with the reference value, the chosen indicators are used to accumulate a specific value [10]. By avoiding the choice of wrong or improper indicators, objectivity can be assured.

$$specific\ value\ K = \frac{actual\ value}{reference\ value} \tag{1}$$

According to formula (2), with the degree of performance of each indicator it is now possible to accumulate an overall-value in consideration of specific weighting [10]. By weighting it is feasible to blind out, to dilute or even to amplify the influence of each indicator when necessary:

$$overall-value\ \ K\ = \frac{\sum_{i=0}^{n}\left(value\ \ K_i\ \cdot\ weighting\ \ G_i\right)}{\sum_{i=0}^{n} weighting\ \ G_i} \tag{2}$$

3.2 "Progress of product development process" and "product's degree of maturity"

These two terms are frequently used synonymic: With a certain progress of the development process a certain product's degree of maturity is expected, although the product's degree of maturity has to be measured with different criteria than the progress of the development process. Due to this fact there has to be established a clear distinction between the both terms "progress of the development process" and "product's degree of maturity", even though during development of a product both aspects have to be involved into a holistic safeguarding. Both the estimation of the product's degree of maturity and the capture of the progress of the development process is conducted by using indicators which provide forecasting progressions and trends, allow recognizing risks earlier and enable the developer to determine the real state of the product development. The next chapters give a short overview and definition of the two terms to be distinguished.

Progress of the development process

The aim of analyzing the progress of the product development process is to achieve objective statements regarding the progress of a project and monitoring consumed time and caused costs [11], [12]. In the event of unsatisfying results, monitoring the progress of the development process offers the possibility to interfere and to stop negative trends early.

Mostly, within the development of a technical system there are a lot of contributors engaged in many sub-processes. Hence, those contributors are – if anything – merely able to estimate the degree of maturity of their own amount of development, whereby a global statement about the progress of the development process is almost impossible. For efficient controlling of important dates and costs, the accurate knowledge about the up-to-date progress of development processes and about the actual achievement of objectives are fundamentals [13]. In opposition to both complexity and necessary effort in monitoring the progress of the development process, as benefit can be named the resulting transparency and thus the opportunity to compensate possible aberrations as early as possible. As possibilities for monitoring the progress of a development process can be mentioned on the one hand the capturing of the amount of accomplished release procedures, and on the other hand monitoring the number of solved problems in comparison to the number of recognized problems. These two possibilities are shown in figure 2 (according to [10]).

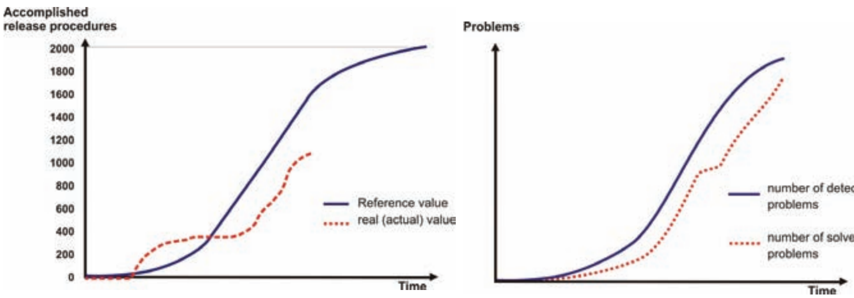

Figure 2: exemplary sketches for accomplished release-procedures (left) and solved problems (right), according to [10]

When controlling the process by the use of release procedures, the progress of the process is quantified analogue to formula (1) by comparing the amount of accomplished released procedures to the number of the release procedures scheduled at that time. Indicators can be released work packets, documents or for example CAD-models of parts or assemblies. When using the comparison of the amount of solved to the amount of recognized problems (right diagram in figure 2) all appearing problems are to be captured and their solution is to be claimed for a certain date [10], [3]. By this comparison it gets possible to deduce a statement about the progress of the development process: Not just the state of problem solving is monitored, but also a forecast gets possible: By means of the appointed dates for each problem to be solved, it is possible to forecast the amount of solved problems within a certain time in the future. But, due to the fact that empirically the amount of problems is increasing with the period of the development process, the final value of solved problems is increasing and hence unknown. Figure 2 depicts the comparison of accomplished and scheduled release-procedures (left) and the comparison of the amount of solved and recognized problems (right).

Product’s degree of maturity

The product’s degree of maturity is the degree of fulfilling the customer’s needs in consideration of additional requirements resulting due to the choice of a certain solution [6]. This definition displays an advanced comprehension of the term “product’s degree of maturity” and takes into account, that there are more properties than just the customer’s requirements relevant when safeguarding a product being developed. In connection with this, it is important to understand, that monitoring the progress of the product development process by means of capturing consumed time and caused costs does not allow any assured statement about the product itself. To assure the quality of the product already during development period, it is essential to supervise and to safeguard the product’s degree of maturity separately. In this contribution the term “product’s degree of maturity” is seen as performance of a product related to its use (analogue to [11]). Hence, the product’s degree of maturity is the captured state of the product concerning defined indicators at an arbitrary moment [10]. Due to iterations, changed target values, unexpected problems and changing indicators during development, the product’s degree of maturity does not proceed linear but is wavering in reality. Figure 3 shows possible examples for scheduled, real and assumed progresses of the degree of maturity [11], [3].

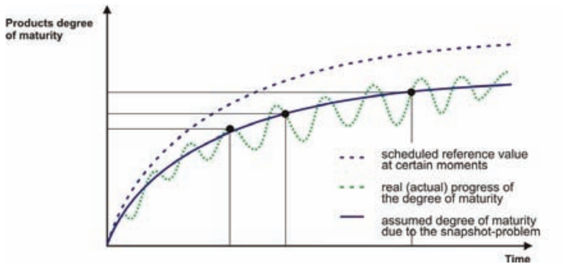

Figure 3: exemplary sketches for the scheduled, real and assumed progress of degree of maturity (according to [11], [3])

Because of the fact, that each safeguarding is a snapshot of a defined moment, monitoring the product’s degree of maturity suggests a certain progress (figure 3). Hence, in the case of disadvantageous dates for capturing, there can result an assumed progress of the product’s degree of maturity, which differs to the real degree of maturity (figure 4): Based on snapshots, an ongoing of the development as scheduled is assumed, although the actual development process does not proceed promisingly. In this case, a needful intervention wrongly will not occur.

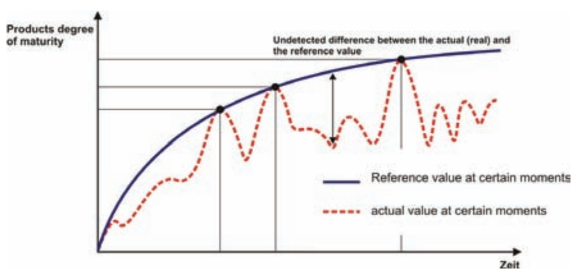

Figure 4: possible undetected difference between scheduled and achieved product’s degree of maturity (according to [11])

Just as well, based on snapshots the progress of the product’s degree of maturity could be classified as critical, although the process proceeds as scheduled. These two examples demonstrate that when safeguarding the product’s degree of maturity the progress of the development process has to be considered additionally. By including the progress of development, not only misjudgments can be avoided, but also an unfortunately established practice can be prevented: Often, near completion of milestones the effort to achieve goals is amplified at accepting quality penalties. In the further progress of the process these arrangements and decisions are detected as not being helpful and are called off, what is equivalent with dropping off in the diagram of the product’s degree of maturity (figure 4).

3.3 Further challenges in safeguarding product's degree of maturity

In the context shown above there are emerging further challenges that a proper methodology for safeguarding product's degree of maturity has to deal with. These challenges and adequate possible approaches for their solution are introduced in the following.

Holistic safeguarding

A holistic methodology for safeguarding of the product's degree of maturity has to exceed a mere observation of the product. It has to integrate the product itself, the related development process as well as all participants [14]. These three dimensions are detailed explained apart in the following.

Product: While safeguarding the product's degree of maturity, the complete product has to be monitored. The widespread practice of monitoring just a few focused amounts of parts is not enough. On the one hand this procedure is based on experience of completed projects (which is not always sufficient available). On the other hand large parts of the product are neglected. Hence, there results a lack of possibilities to recognize and to correct aberrations as early as possible. A safeguarding based on several product structure-levels, for example based on the three levels "part", "assembly" and "overall product" is strongly recommended. Each level has to be safeguarded based on adequate indicators. At this it is important to respect the fact that a superior level of product structure has not just to account on the sum of the inferior level, but has to consider interdependencies and connections between the lower levels as well as properties that are emerging within these higher levels. (e.g. joining techniques, opposite disturbances, impacts and so on…) [3], [11], [14].

Process: A holistic safeguarding of the product's degree of maturity has to be extended on the entire development process period. Since starting safeguarding the product's degree of maturity not before the phase of designing is in contradiction to the demand of safeguarding at an early stage, this means that already the phase of conceptualizing has to be involved. This is important, because in the beginning of the product development process, unplanned actions are much easier than interventions in phases in which the product no longer can be designed, but merely can be optimized.

Participants: When safeguarding the product's degree of maturity, it is essential to involve all participants, contributors and existing suppliers, too. Only by involving the persons responsible for the development work, an authentic statement is possible. But not just each person involved in the development process, but also all stations which the product passes through during its lifecycle are to be considered and involved. Assessing the product's degree of maturity can be done from many different perspectives: The product can appear "mature" in the perspective of the development department (ideally based on customer's requirements), but can be assessed as absolute "immature" and insufficient for packaging and logistical purposes. Consequently, there is to establish a specific value for each perspective to be considered, which allows safeguarding the product regarding certain properties. As possible perspectives there are to be mentioned e.g. development, purchasing, manufacturing, production, assembly, transport, logistics and recycling. Such perspective-specific safeguarding is in the end a validation of certain criteria in terms of Design for X.

By appropriate choice of indicators it gets possible to integrate these three dimensions "product", "process" and "participants". To offer the possibility to identify the reasons of appearing aberrations, it is important to guarantee the traceability of summarized indicators when coupling product and process in terms of holistic safeguarding.

Appropriate granularity

To satisfy different necessities of the level of management and the level of responsible developers, an appropriate methodology has to provide an adaptable granularity for displaying information. Hence, according to requirements, it is possible to get a fast overview as well as very detailed information about a certain aspects. Due to the multiplicity of possible indicators for each level of the product structure, there results the possibility of a highly detailed safeguarding of the entire product in specific perspectives from each involved participants along all the development process period (cf. product, process and participants as aspects for holistic safeguarding). Significant specific values can be accumulated by summarizing certain indicators [15], [3]. This copes with specific needs of each level between management and responsible developers. But, due to the fact that an overall-value does not provide any traceability of its buildup, it is essential to assure a later retracing of weight and magnitude of each contributor when summarizing certain indicators to "superior" specific values.

Safeguarding using uncertain data

A further challenge when estimating the product's degree of maturity is the fact that uncertain data about the product being developed are not circulated in order to avoid hasty activities based on such uncertain and immature data. Thus it cannot be guaranteed that all information about each indicator is always available. The use of fewer indicators in turn leads to inaccurate or even incorrect specific values. This problem can be solved by using a multi-level release procedure according to [3]: The first level denotes the documents as mere information without giving guarantee for being certain, which means that fundamental changes can still occur. The second stage indicates a near-series state of development, while the third stage equals an obligatory release without any restrictions. Suitable as guideline for estimating the level of release is an approach to classify the reliability of development data presented in [16]: This classification of reliability is based on five criteria: "certainty", "precision", "stability", "updating" and "completeness". By using this multi-level release procedure, all piece of information can be recognizably marked as "immature" or "uncertain" before being referred to any receiver. Hence, each receiver is able to estimate the certainty of given data by himself and thus is able to decide, whether the given data are an appropriate basis for further development.

Unknown final value of used indicators

When estimating the state of a product being developed it is important to determine the final value which denotes the development as finished. According to [3], at least three different aspects can be distinguished: On the one hand the product development can be regarded as finished by the fulfillment of all customers requirements and thus with the definition of the last product characteristic. On the other hand providing the documents for production and manufacturing or e.g. instruction manuals can be seen as part of the product development, even if the product itself does not experience any progress in sense of an increasing product's degree of maturity during these procedures. Thus the product development would be finished after completion of the product documentation (similar to the VDI-Guideline 2221, [17]). Since the product is being developed further during series (e. g. technical adjustments or application of new materials), the third (and most extensive) perspective regards not only the start of the production phase but also all possible changes during series production as part of the product development. Another case of unknown final value is the case of an adaptation or a change of existing constructions: In this case the final value of parts (or documents) to develop (or to change) is not equal to the amount of all parts (or documents). Otherwise, if there is just a little amount of parts to change, the value of the product's degree of maturity would start at almost 100% in the beginning of the development process. In this case the required value has to be equal to the number of parts to be changed. In case of a totally new development often the number of parts to be developed is unknown until the product structure is being developed. In these cases sometimes just a qualitative estimation of the progress based on the differences between two development states is feasible.

Individuality of used indicators

Indicators as for example the number of released documents or fulfilled requirements will not increase significantly until the last phase of the development process. Furthermore it is to be noted that different indicators are relevant at different times, thus they are to be considered for a different period of the development process and consequently are variable weighted during the development process. For example an indicator for accomplished release procedures is used earlier in the development than an indicator which compares the actually number of items of a product produced per period to the originally scheduled value. However, other indicators like „weight" and „manufacturing costs" are relevant over the entire development process. The individual trait of each indicator (late increase, different relevance, individual duration of validity) hinders the close-to-reality and traceable monitoring of the project progress. Hence, this trait is to be considered when selecting indicators. Dynamic weighting of indicators can be seen as a possible approach to adapt safeguarding to different factors: On the one hand the subjective estimation can be simulated by weighting an indicator of lower degree of maturity heavier than an almost fulfilled indicator. On the other hand it is possible to fade out some not significant indicators. By using this procedure, the attention can be focused on indicators that are less fulfilled or immature.

4 REPRESENTING THE PRODUCT´S BEHAVIOUR BASED ON PROPERTIES

As mentioned above, in this contribution the behavior of a product is seen as the relevant measurement to asses the product's degree of maturity. In section 2 of this contribution a description of the product's behavior based on its properties and characteristics was introduced. According to that, to asses the behavior in different conditions of use (and thus to evaluate the degree of maturity), two important things have to be known: On the one hand the mode and conditions of use and on the other hand the product's properties. The mode of conditions and use is a result from the later use of the product, whereas the product's properties – as shown in section 2 – can be determined from the configuration of characteristics by conduction of different analyses.

4.1 Connecting characteristics and properties

Due to the fact that – according to section 2 – the product's properties are a direct result of the configuration of characteristics, the connection between characteristics and resulting properties is an appropriate possibility to evaluate the product's degree of maturity. This can be done by arranging the characteristics line by line and the properties column by column in the form of a matrix. To sign the characteristics as being connected with the related properties, the respective part of the matrix has to be marked, either by setting a simple cross or by weighting the influence stepwise between for instance the levels "-5" and "+5". A negative value signalizes a contrariwise interaction between the chosen characteristic and property, whereas a positive value signalizes a positive correlation, and a weighting on level "0" denotes the characteristic and property as not being correlated.

4.2 Interactions between characteristics

As mentioned above, some characteristics of the product are connected or parametrical associated to other characteristics, thus a change of those characteristics generates chain reactions. To handle these interactions in terms of a change impact analysis, an approach using a variation of the method "House of Quality" was shown in [4] (figure 5). This approach allows connecting characteristics and properties and it is appropriate to depict interactions between characteristics. But with this approach, these interactions are merely detected just within one single part. In the example shown in figure 5 the property 1 is result of characteristics 1, 2 and 3. For example characteristic 3 is depending on characteristic 2 and 5, and characteristic 3 influences the properties 1, 2 and 5.

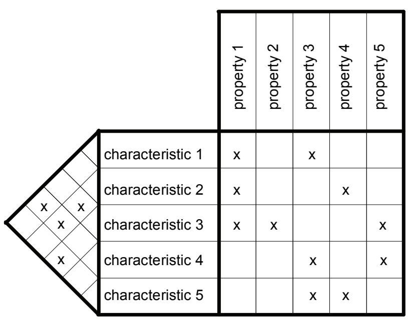

Figure 5: Approach for connecting properties and characteristics in terms of an change impact analysis based on the CPM/PDD-approach (according to [4])

Aligning more than one of these particular matrices in just one single superior matrix (exactly one matrix for each part of the product) allows depicting also interactions between characteristics of different parts, thus the detection of connections across the entire product (figure 6). To keep up clearness, figure 6 shows an exemplified matrix for a product existing of just three parts with five properties and five characteristics for each part. It is important to highlight that this approach is neither limited to a maximum number of parts nor it is subjected to the condition of an equivalent number of characteristic and properties. This method provides an instrument to comprehend all subsequently necessary changes before conducting any change of characteristics.

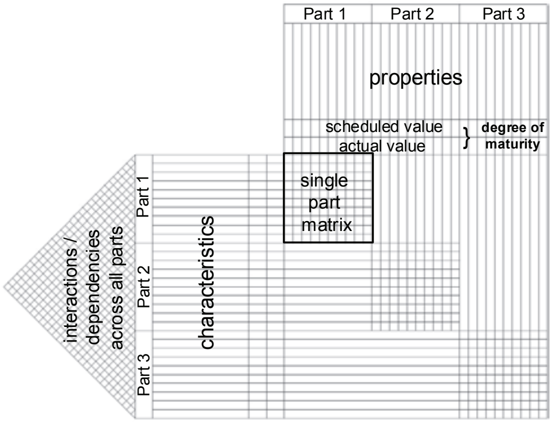

Figure 6: Approach for depicting interactions between characteristics across the product

4.3 Interactions between properties

The matrix shown above is not able to consider higher-level properties that are emerging from manufacturing or arise out of interactions between parts or subsystems. Figure 7 shows an opportunity for consideration of these properties by providing an own matrix on each level of the product structure.

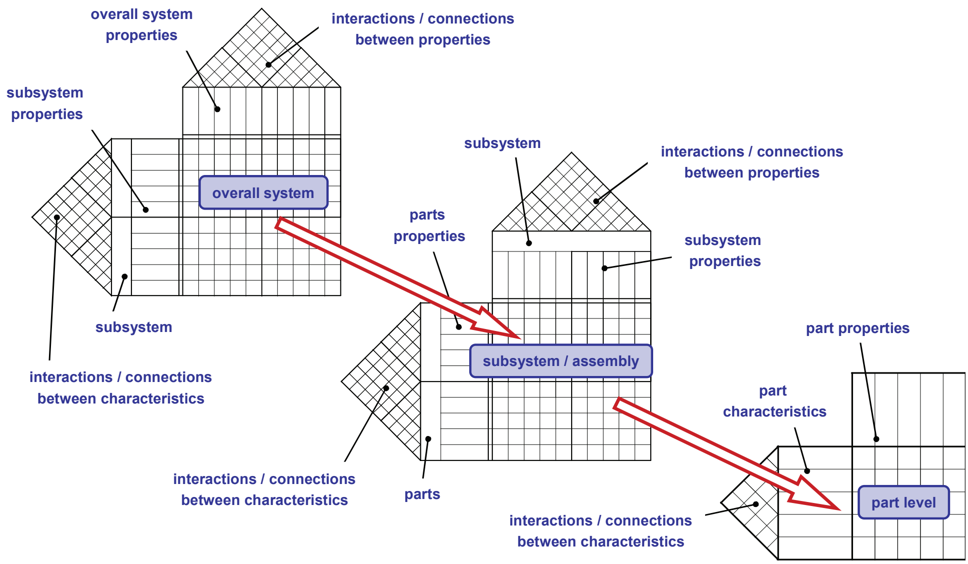

Figure 7: Approach for connecting properties and characteristics and for depicting higher-level interactions between properties among each other across the whole product structure

Each of these matrices depicts an own level of the product structure (here: part level, subsystem and overall system). Each level aside from the part level is able to depict (a) interactions between characteristics, (b) interactions between properties and (c) connections between characteristics and properties. Thus it gets feasible to retrace each characteristic's influence on properties of part level, subsystem level and even up to the overall system level. So it gets possible to depict all connections between characteristics and properties even across the entire product, which is a very important feature: For example let's have a look at a bolt's diameter and the breadth of the related slot in a sheet metal: If an analysis showed the breaking of the bolt under given load, one possibility for strengthening the bolt is to amplify its diameter, what causes also a broadening of the related slot in the sheet metal. Result of this broadening could be the sheet metal's weakening and thus its deformation under load. This simple example shows the importance of consideration of these connections and interactions also across different parts. So, the connection between characteristics and properties as well as the consideration of all connections and interactions between the characteristics and properties across all parts of the product can be achieved by using the depicted framework.

By demonstrating the changes of the product's properties, this framework enables developers to evaluate all influences of possible design changes a priori and to assess subsequent necessary changes and influences on resulting product's properties. Hence, it becomes possible to conduct only those changes, which entail just consequences that are foreseeable and are manageable easily.

5 DRAWING A CONNECTION BETWEEN DESIGN ITERATIONS AND THE PRODUCT'S DEGREE OF MATURITY

By using the definitions and approaches shown above, it is possible to draw a connection between design iterations and the product's degree of maturity: A consequence of the introduced definition of the product's degree of maturity is a decreasing product's degree of maturity in the case of new requirements or changes of boundary conditions. In such cases the necessity of design iterations can arise. Thus a decreasing product's degree of maturity can be seen as an appropriate indicator for the necessity and thus as trigger of conducting design iterations. On the other hand, result of successfully conducted design iteration will be an increased product's degree of maturity. Thus to sum up, a decreasing product's degree of maturity indicates the necessity of design iterations, and from successful iterations result an increased product's degree of maturity.

Hence, by providing preventative estimation of the product's degree of maturity before conducting any design iteration, the introduced framework establishes a connection between design iterations and the product's degree of maturity. Thus design iterations can be identified as unnecessary, if they do not have any advantages, or as helpful since they allow an early increment of the product's degree of maturity. The shown dependencies between iterations and the product's degree of maturity allow the formulation of a specific value for evaluation of the efficiency of design iterations. When comparing the product's degree of maturity before and after conducting design iteration, it gets feasible to deduce the efficiency of the considered iteration analogue to formula (3):

$$efficiency\ of\ considerd\ iteration = \frac{degree\ of\ maturity\ before\ iteration}{degree\ of\ maturity\ after\ iteration} \tag{3}$$

In distinction to the common definition of technical efficiency, the introduced efficiency of design iterations does not vary from 0% up to 100%, but indicates the value, at which the product degree of maturity gets multiplied by conducting the considered design iteration. Hence, it is not reasonable to evaluate an iteration based mere on this specific value. Rather this specific value is an appropriate way to compare the influence and the efficiency of two or more considered changes, thus design iterations. This value of efficiency can provide a support to choose only those changes that achieve the best result in increasing the product's degree of maturity by assuring holistic consideration of the whole product.

6 BENEFITS OF THE INTRODUCED FRAMEWORK

The introduced framework allows forecasting the influences of each possible design change on every single property of each part as well as of the overall system, which promotes purposeful enhancement of the product's degree of maturity and avoids unnecessary iterations: For each change the effort of subsequent changes, the influence on certain properties and hence the influence on the overall-degree of maturity can be evaluated. Based on this estimation it is now possible to conduct only those iterations, which are really beneficial to the overall-degree of maturity by causing little effort.

Beside the desired improvement of certain properties, some changes may cause the worsening of other product properties, which is noncritical and still in line with the requirements. Although this change is maybe absolute necessary, normally the developer will hesitate to conduct such a change. But by demonstrating all influences of any change on all properties of a product, this approach helps to enhance the overall-degree of maturity purposefully. Iterations, which worsen certain properties (in line with the requirements), but in sum are beneficial to the overall degree of maturity, are evaluated as helpful and recommended, since other more important properties are significantly enhanced. This

allows forecasting the product's degree of maturity, assessing the necessary effort before conducting any change and helps to identify and to avoid unhelpful and unnecessary iterations.
When using this approach to evaluate and to forecast the product's degree of maturity, it is possible to meet the challenges shown in section 3: By involving all properties and all characteristic of each part of the product, claiming for holistic safeguarding is pushed. By the possibility of monitoring each conceivable indicator and to summarize those to specific values an appropriate granularity of reporting can be ensured. Safeguarding with the use of uncertain data can be managed by using the shown multi-level release procedure and - if necessary - by attaching a certain value of insecurity to each analyzed property. The claimed individuality of used indicators can be ensured by weighting indictors in dependency of the progress of the development process and for example the chosen DfX-strategy. Thus it can be guaranteed that each indicator is used in its range with the best informational value.

6 CONCLUSION AND OUTLOOK

The aim of this contribution was to introduce a framework for the evaluation of design iterations and for assessing their effects on the product's degree of maturity. For this purpose, firstly there was to establish a consistent understanding of the product's degree of maturity. In this contribution, the product's degree of maturity is understood as fulfillment of required products behavior under consideration of the mode and conditions of use. Therefore, the terms "function," characteristics", "properties", and "behavior" were defined and a description of the behavior of a product based on its characteristic and properties was introduced. A clear differentiation between the terms "progress of the development process" and "product's degree of maturity" and their definitions were given, and some fundamentals for the evaluation of the product's degree of maturity were demonstrated. Furthermore, a connection between the product's degree of maturity and the conduction of design iterations was drawn. Based on this connection a possibility for evaluation of the effects of design iterations on the product's degree of maturity as well as a specific value for appropriate measurement and evaluation of the efficiency of design iterations was proposed.
Objectives of further work could be the connection of certain characteristics with their resulting properties and the exploration of connections and interactions between characteristics on a specific example. The implementation of the so called feature-based product development and thus the use of analyzed and well-known "construction elements" (for example geometrical constituents of the products shape) are seen as appropriate to provide the necessary connection between characteristics and properties. Development by using complete parametric design could provide constraints, connections and interactions between the characteristics as they are needed for appropriate application of the introduced framework. Thus, maybe the feature-based and fully parametric conducted design could be the key for an automated and holistic evaluation of the product's degree of maturity on the one hand, and for the promotion of helpful design iterations and the avoidance of unnecessary iterations at the same time on the other hand.

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