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ON DETERMINING A PRODUCT'S PROCESS RELATED TO THE DEGREE OF MATURITY

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1. Introduction

Creating an effective product development process is acknowledged as an important competitive factor for the manufacturer since this includes the possibility of translating innovative ideas into marketable products. In practice, it proves to be very difficult to pre-plan the details of product development since the process involves a high degree of creativity, that cannot be prestructured very well. Nevertheless, in order to be able to support engineers in the process, an approach is followed which views the process of product development as a closed loop and thereby reduces the progress of the process to a description of and an aid to decision making. This decision making is influenced by a multiplicity of factors: the vision and strategy of the business, the specifications of the specific project (procedural-organisational and product specific specifications), the know-how in the business and in the development department etc.. For product development purposes, product specific information is indispensible for precise decisions about the progress of the process. That is, statements about which data is available for the product, which comparative data of earlier or similar products can be used or how product-relevant information can be accessed. Decision making is to be expected during the entire development process and increasingly differentiates itself in the course of the product's realisation.

This article focuses on statements about products and their realisation which are to be regarded as an essential element of the decision making's foundation in the process. Here, the product's level of maturity is generaly taken as the level of product realisation. However, with today's approach, this proves to be insufficient, precisely for interdisciplinary products since the focus is primarily on geometrical considerations. The aim of considering the materity level must not only be to compile which components are available in which realised form, but how far the current state of development expresses the required product functionality. Furthermore, this knowledge is to be set in the context of the process's progress. Here of course, the customer's requirements or wishes are to be taken into account as important criteria for comparison in order to describe the desired functionality of the product. Here also, additions and enhancements of the customer's requirements contribute to the definition of the product's description which result from the problem-solving process and the translation of these customer requirements into the appropriate technical parameters.

This state of development should be described using a function-orientated maturity level, where the concept of function targets the product's functionality. What is precisely understood by this and which principles are necessary, are to be specified.

2. Customer requirements and product attributes

The product development process is characterised by its high complexity whose course can only be pre-planned with great difficulty. The pre-planning is based on incomplete information and data, with which the development commences [1]. Only its realisation, by means of generating information and knowledge about the product, permits statements about the next process step. With this in mind, the procedure in the product development process is to be reduced to decision making. For this purpose, the product development process is reduced to a closed loop where the progression of the process then depends on how far the stipulated requirements conform with the acquired attributes at a defined point in time (figure 1).

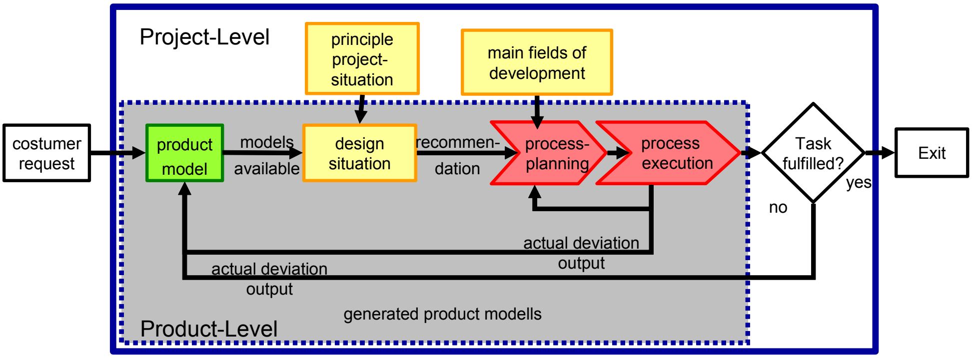

Figure 1. Generic process model for specifying the decision making (according to [2])

Besides the procedural-organisational information at the project level, specifying the decision making also requires information about the product itself. For this purpose, the customer requirements represent the prerequisites at the intiation of the development process. In the course of the development, these are supplemented and replaced by the generated product data. Only by mutually considering the product data and project data can suggestions be derived for further process steps. As a result of carrying out the process steps, features arise which are to be translated into attributes [according to 9, 8] by a suitable analysis procedure in order to compare them with the desired requirements. Appropriate methods and tools exist for the classical analytical procedure which are employed and which depend on the requirements or the phase of the actual developmental stage.

For example, FEM can be implimented as an analytical procedure in order to derive statements about the vibrational behaviour and therefore about the acoustics. Computational methods aid strength analyses, visualising methods permit statements about utilising design space or potential collisions. The results of the analysis stages are normally compiled in documents e.g. results files from a FEM analysis, Excel-lists with the computational results, CAD-files with geometric models. These documents are available to the developer at all subsequent process stages and are designated [3, 4] in the following as partial product models (pPM). In contrast to the integrated product model, the partial product model depicts only a partial aspect of the product, namely that which has developed within the framework of the associated process stage.

The interesting fact here is that the pPM can be assigned to actual process stages [3]. This supports using the maturity level as a product specifying statement in relation to the expected state of the project as a procedural-organisational description of the product development process.

3. Description of a product's maturity level

In the literature, the concept maturity level is used in many different ways, e.g. quality, time or costs in the product development. A thorough examination of the diffent meanings can be found in [5]. Generally, one can say that with maturity level, both the product as well as the process should be verified at a stipulated point in time by means of indicators that depict how far the customer's requirements are fulfilled. This monitoring system generally comprises of statements about personel resources, costs and/or time. Here, reference to the product results from mere geometrical considerations. This means: Geometrical elements are compared either by counting parts and comparing with a pre-defined number of parts, or by verifying the parts or geometrical elements to the effect as to how far they were already specified and completed. The causes of the restricted ability of maturity level statements, as found in the current literature, lie in the structure-orientated view of the product. In domains, structural statements are very diverse and therefore very heterogeneous. In IT, a structural description can be a source code; in electronics, this corresponds to a circuit diagram; mechanical engineers focus on conventional geometrical considerations. A some what more generally valid statement, also mainly for interdisciplinary products, can be found in Weber [6]. He designates maturity level as an estimate of the product's use related performance. It is also important that a maturity level statement is always comparative and requires a reference. For this purpose, there is a paucity of generally valid and reliable indicators.

- How does one sufficiently define the product functionality? This is ultimately required in order to make a comparison with the reference value (question of indicators). In connection with this is the fact that maturity level statements are currently not always associated with clear goals. That is, the question; when can the product development be considered conclude, should be clarified.
- How can one guarantee that the product functionality is assured by a summation of the structural elements? This is particularly valid for components from other domains, whose form of specification/description can not be made by geometrical statements, but which is indispensable for the completion of the product’s functionality.

As a solution method, the more generally valid approach of a behaviour-orientated specification should be implimented. With this, one assumes that there are structural elements to be examined, with which those characteristics are associated. From the general black-box-approach, the system's or sub-system's behaviour is specified using the transfer of the input parameters into the output parameters: The form of this transfer function depends on the stipulated structure. The aim of this approach is to extend the structural statement to include a behavioural statement. The behaviour can be directly transferred into characteristics which are, in principle, compiled in the list of requirements. Moreover, additional characteristics can be derived with a more precise and detailed analysis, to extend them and, if necessary, the list of requirements in order to sufficiently specify the product’s functionality and to guarantee the quality. Here, the key issue is that where one has defined a structural element for the function's purpose, the function can be inferred from the behaviour. Moreover, additional functions can be derived which will have both positive as well as negative effects on the product’s functionality.
The attributes, diameter and length specify, in a simplified form, the structure of a geometric element to which the function "torque transmission" can be quite generally assigned. Using a FEM or analytical computations, the strength of a shaft can be inferred from the structural element with the aid of the material's mechanical properties, which in turn permits statements about the ability to transmit pre-defined torques that correspond to the list of requirements. Furthermore, other functions, such as "shaft bearings" or "shaft seals", are more explicitly specified.
The notion arises from this known representation, to determine a product's maturity level based on a functional or behavioural-orientated approach. Therefore maturity level is defined as follows:
The maturity level of a product is the level of the requirement's conformance from the list of requirements (customer's view), which can extend to additional requirements that arise from the choice of the solution's principles (engineering view) [7].
For multidisciplinary applications of this definition to process-accompanying and characteristic-orientated maturity level statements, it is necessary to clarify the following questions: (a) Usingm of the characteristic-orientated product specification for the degree of maturity statements:

- How does one obtain the characteristics which arise from the structural stipulations? How can these be derived from the generated results?
- How can one define the "finished" product, if one assumes a dynamic list of requirements?
- Is a specification of characteristics sufficient in order to depict the product’s degree of maturity?

Answers to these questions are to be given in the following section.

4. On the function-orientated determination of the degree of maturity

In the results of an analysis stage, the product's characteristics are determined from the defined attributes. The choice of the analysis procedure is thus selected by the developer so that the generated attributes aimed at the characteristics or requirements are examined. The known values from the list of requirements are accordingly available as comparative values for a maturity level estimate.
What then can the result be of such a comparison of requirements with the characteristics generated from the attributes? On the one hand, one always makes a comparison with only sections from the requirement's list. It is not possible to compare the totality of all requirements with the generated characteristics based on the pPM since, invariably, only definite attributes are considered by the analytical procedure. The process stage, within whose framework the analytical process is carried out, targets a preconceived characteristic that should be generated at an earlier synthesis stage. Initially, only this characteristic is available for the comparison. On the other hand, the main result will, in any event, be a statement about whether the preconceived characteristic was established or lies within acceptable limits, as the case may be. Here, the challenge for the developer consists of culling that data from documents, which actually reflect the characteristics. It is the developer's task, based on this direct comparison, to consider whether it is sufficient to customize the specified attributes in order to adapt the characteristics to the requirements. It maybe necessary to reconsider the basic solution approach. For this purpose, nuances are also possible. Initially, tests can be carried out to find which modifications to the principles of the solution possibly lead to the required results for the partial function under consideration. If this is not sufficient, the principles of the solution, as such, must be questioned.

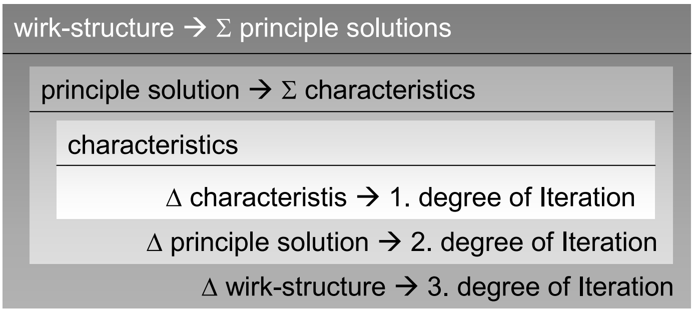

Figure 2. Iterations in product development process

Furthermore, the overall behaviour of the product can be analysed, which results from the pPM. By this means, special features of the behaviour can be discerned which either co-specify or co-realise other already preconceived characteristics or rather encounter new, hitherto unconsidered characteristics. These new characteristics must be followed up in the enhanced product development process.

4.1 Determination of the data for comparison

As mentioned in the specification of the degree of maturity, this is invariably determined for a product in the process context as a comparative value. For the development process, this means that prior to the development, which basic characteristics sufficiently depict the product's functionality must be stipulated. Generally, this is achieved by means of the requirement list's definition. Here, modifications are conceivable because the customer's wishes change during the course of development. Parallel to this and within the framework of agreeing the milestones, it can be specified, which conformance level of functionality should be reached at this point in time, so that the functionality, as a product-specifying criterion, can reasonable contribute to both the process formation and the decision for subsequent process stages. This is ideally carried out on the basis of a hierarchical characteristic specification, which is introduced in the next section. The fundamentals for this form the results which can be expected from the conventional analytical tools for the development phase.

The most important question to be clarified is how the characteristics can be culled from the pPM. It was already implied in section 2 that generating the characteristics is a conventional result of the analytical process, for which a multiplicity of methods and simulation tools are currently available to us [8] which can, according to the stated problem, be implimented. Independent of the analytical tool that is ultimately relevant to the stated problem, the expected behaviour of the product (as a function of the developmental state) must emerge from the analysis' results. In this connection, the area of expertise, from which the solution approach arises, also plays a role for the purpose of an interdisciplinary development. Here, the level of detail in the behaviour specification is dependent on the state of development. This is reflected in the currently available simulation tools.

In the early phases (concept/design), one attempts to verify the product’s functionality for the chosen principles of solution by focussing on the input and output parameters, which are coupled with each other. Here, the precise structure used to arrive at the output from the input parameter, only plays a subordinate role. Already with comparatively simple models, one is currently in a position to also deduce additional or occuring characteristics apart from the required characteristics. These additional characteristics identified by the developer, on the one hand contribute to the refinement of the existing model, whereby the product functionality can invariably be specified in more detail. On the other hand, the characteristics update and supplement the requirement's list (see section 4.2). Predefined partial functions are continually actualised, for which it is, in turn, necessary to find solutions or which must be manifested by the structural stipulations, as the case may be.

With increasing product realisation in the design and preparation phases, the transition takes place from behaviour refinement to the actual stipulation of the structural attributes, where its definition must be guaranteed by the function (which, in turn, arises from the required input and output parameters). The character of the anaylical tools change, one now increasingly needs field-theoretical modelling approaches, with which one is in a position to depict the product's complete physical nature since these approaches incorporate the structure in appropriate detail. The output, that specifies the product's behaviour, cannot now be directly extracted from the results but rather values are sought which can be considered as a typical measure for the characteristic. In this way, a statement about resonance frequencies will permit inferences about the stiffness of a component/system; a computed von-Mises stress permits inferences about strength and thus a component's load bearing capacity.

It is necesary to infer actual product characteristics from individual computations or analytical values, as the case may be, as the engineer explicitly examines and evaluates critical locations which are known to him from his experience. Parallel to this, results from the overall structure are to be examined for critical values since, here again, impairments in the product's functionality can be recognised, which either influence, in some way, other characteristics or, in certain circumstances, bring about new characteristics.

Absolutely crucial in evaluating the analytical results is that data is indeed generated which possess a certain objectivity. However, since the data is interpreted, evaluated and placed in the context of results from another concurrent stage of analysis by an engineer, a target/actual comparison statement about the characteristics for specifying the product's maturity acquires a certain subjectivity. In this respect, factors which reflect the developer's level of knowledge, his professional experience and also his practical knowledge of the analytical tools invariably play a role in the results of a target/actual comparison. This subjective part must contribute to the partial aspects for process formation mentioned in the introduction, but is not thematised here.

4.2 On deriving degree of maturity statements

By means of the procedure described in the previous section for determining the characteristics and the problems which arise during the identification and assessment, different statements about the maturity level can be derived for the course of the process and each typical product feature. With regard to the process support, the most important aspect is certainly the utilisation of the determined characteristics for specifying the progress in the course of the development.

In order to obtain statements about this, tests can be initially carried out to determine which of the requirements from the requirement's list have been fulfilled. Here, the comparison should contain an absolute statement, that is a clarification, whether the generated characteristics lie within the demanded limiting values from the requirement's list. One such statement is certainly dependent on the development phase, in which one is situated in the product's development. The results of the conceptual phase yield solution principles from which it will be apparent if, for example, the necessary machine's time-distance characteristics can, in principle, be reached by means of the gear-box solution used. Not until the design phase, using the geometric definition of the gear-box elements, will it be possible to estimate if and how specified time-distance values will be adhered to.
Parallel to this, the analyses of the functions or the characteristics, as the case may be, at the end of the process stage produce statements about the additional characteristics which are either co-influenced by the prescribed characteristics or they additionally arise through the choice of the solution. For example, with the geometric definition of the gear-box elements, the proportions of the design space will be influenced, the weight changed and additional functions arise such as the "gear-box's sealing" in order to guarantee lubrication and to avoid leaks. A complex treatment of the characteristics almost leads to a graph which, on the one hand, shows a hierarchical structuring and, on the other hand, must simultaneously reflect the linking together of the characteristics to depict the dependencies. Therefore, a comprehensive treatment of the characteristics demands a "dynamic" list of requirements which is not only in a position to accept addition characteristics but must, above all, also document the relation between them.
From this is becomes clear that the characteristics show diverse levels of conformance which is informed by the level of detail provided by the development phase (figure 3). Bearing in mind that the company is based on conventional process models whose stages are terminated with milestones or stage gates, it should be considered whether these can be exploited for determining the process related maturity level. This would provide a statement about both the product's and also the process's progress. The difficulty lies in the derivation for the milestones from the product's functionality demanded by the requirement's list. In contrast to the requirement's list, it can be assumed for these comparative values that, precisely for later milestones, a realisation of the comparative values is necessary with each milestone.

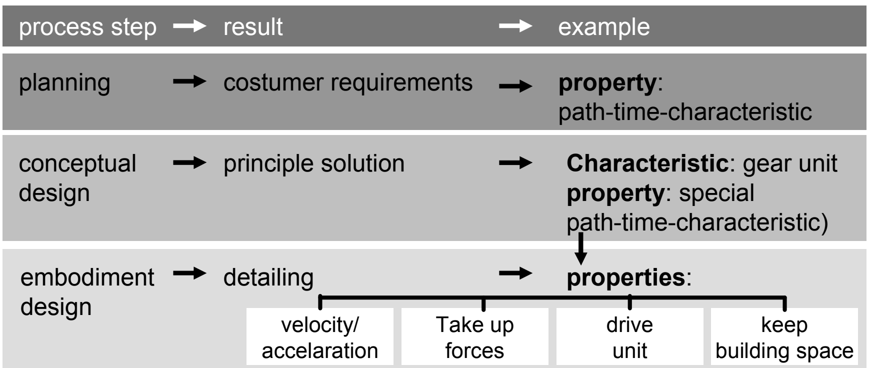

Figure 3. Coupling of previous stages in the product's development with characteristics

On reflection, there also arises a process dependent structuring of characteristics. At each advancing step, which consists of a series of process stages, characteristics are partitioned further. From these partitions, the engineer must ultimately derive the next step in the development process. However, these partitions can, to a certain level, be conceptually anticipated, by which the following process stage can, to a certain level, be pre-planned. As the example in figure 3 shows, the subordinate characteristics target specific process stages, in particular necessary computations, CAD-constructions or the engine design. It is of interest that interdisciplinary aspects, that is, the integration of other specialist areas, result in a development process entirely alone from the form of representation. For one thing, this facilitates the integration of the specialist areas, but above all, clearly emphasises the global interrelationships not only between the characteristics but also between the specialist areas. For example, this must be used to specify the requirements in the domains and to explicitly describe the interfaces. Moreover, a detailed consideration of the characteristics and, above all, the integration of the results from the possible iteration steps (figure 2) permit a sensitivity analysis which emphasises the importance of individual characteristics for the total functionality of the product.

5. Summary and perspectives

This contribution has shown how the decision about the progress of processes and about the next process stage to be selected can be supported by using appropriate information about the product's functionality. On the one hand, by choosing function or behaviour-orientated representations of product specific development results, as the case may be, a successful comparison of the actual customer requirements as a reference value is made using its characteristics. On the other hand, interdisciplinary solution approaches and development results can be considered and implemented for the definition of the development situation. It is necessary to realise this approach in the next phase. The focus is on the dynamic configuration of the requirement's list and on searching for methods, with which the characteristic's documentation will be representable with respect to both the hierarchical structuring as well as the detected interactions. This representation is in such a way that the development's progress can be followed. Parallel to this, it is necessary to compile operating guidelines which support the developer in deriving the characteristics from the attributes, where here different analytical approaches, which arise from the procedure model, are to be taken into account.

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