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Requirement oriented process planning and configuration

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Abstract
Flexible process planning is necessary in order to design a product on the basis of individual requirements. Existing methods provide good approaches to describe processes but the planning itself is hardly supported. Therefore, a process planning methodology was conceived which allows a requirement oriented process planning and configuration. New processes can be synthesised where necessary by linking required design activities to the product structure. By the same principle existing process modules can be easily selected from a database according to given customer requirements.

Keywords: design processes, process planning, process modules, configuration

Introduction
In the recent years activities in research and practice more and more have focused on process improvement. It has been realised that integrated processes lay behind all value adding activities of an enterprise and that controlling the performance of these processes is crucial for the efficient realisation of the corporate strategy. But not only well defined business processes have been regarded here. As well, design processes have been investigated, which naturally are unstructured and cannot be planned very well in advance. A vast number of methods for improving the design process (e.g. process modelling, planning, and reengineering methods) as well as domain specific process models were developed to support the designer in planning and controlling the product development.
These process methods play a particular role in variant and change management. Here, stable and well structured processes are necessary to handle the complexity of changing requirements as well as the manifold interdependencies between the product elements and between product and manufacturing process. During the last years the number of product variants has increased strongly. Growing market pressure and toughened competition forced companies to develop and produce more and more variants. Again, a high number of variants and stable processes are contradicting. Therefore, the complexity of design, manufacturing, and sales processes has increased strongly. Since the mid-1990ies mass customisation is seen as a new strategy within variant management [1, 2]. Here, the product shall be adapted to individual requirements of the customer in an individual design process [3]. By designing flexible product structures, integrating the customer directly into the value adding chain of an enterprise, and applying new manufacturing technologies mass customisation is also seen as a paradigm shift in handling the complexity which comes along with late product changes [2, 3]. However, there is still a lack of methods that support planning the individual design process according to the respective requirements. While some of these individual design

processes can be planned in advance, others have to be considered in the particular case on the basis of the individual requirements [3].
The planning of these so called adaptation processes [4] shall be regarded in the contribution at hand. The approach which is discussed here bases on the use of (standardised) design process modules, which are known from conventional process planning methods, e.g. the integrated planning of design and manufacturing processes [5]. Similar to product configuration, these process modules shall be put together according to the specific requirements of the process. Yet, the presented method cannot only be applied for planning individual adaptation processes but for planning product changes or new product development processes too.

Methods of modelling and planning design processes

In the following section the state of the art of methods to plan design processes shall be regarded. As well, the concept of process configuration is introduced and the prerequisites for a requirement oriented process planning shall be drawn up.

Challenges in planning design processes

Naturally, it is difficult to plan detailed design processes in advance. Design processes are characterised by shaping the design problem step by step. Intermediate results influence the further process strongly. Because of changing external and internal conditions design processes have to be planned in a flexible manner. That means existing process models (e.g. [6]) have to be adapted to the specific requirements and process conditions of a design situation. In figure 1 influencing factors on the design process are shown [7]. These factors have a massive influence on the selection and execution of certain activities within the design process. In the contribution at hand especially the influence of the design problem, i.e. the specific requirements, on the design process is regarded.

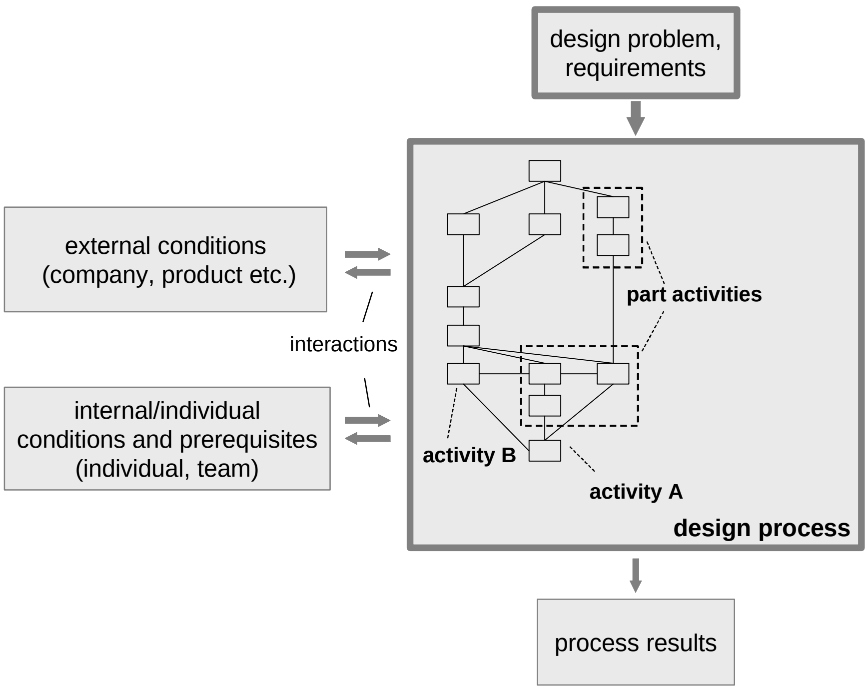


Figure 1. Factors influencing the design process [7]

Another challenge in planning design processes is to find the right degree of detail, in which the processes are described. There is a contradiction between universally valid and

contextually applicable process models that support an upcoming process decision [8]. Because of the changing face of design processes, very often only general process models are proposed, e.g. [6, 9] or some stage gate models in automotive industry. These general procedural models have to be detailed and adapted to the situational context accordingly. Likewise very detailed process models, which explain design activities on a more psychological level (e.g. the Test-Operate-Test-Exit pattern [9]), do not support the designer in making process decisions in a certain situation with given design requirements and a given product structure.
As well, most of the process models are product independent. Even though a lot of domain specific process models where developed in the recent years especially for the development of mechatronic products [10] these models do not take product specific process requirements into consideration (e.g. the necessary product structure and design).
In conclusion a process plan must fit to a specific situation, which is determined by the design requirements, the product, and the boundary conditions, and it should have the right detail to support the required design process. Predefined process models, even if the can be adapted to a specific situation, might not help here. Rather it is necessary to plan the design process according to its requirements in each specific case. However, the proceeding of process planning can be standardised. Such a method shall be introduced in the contribution at hand.

Methods of process modelling and planning
A first approach to standardise the process planning is to use standardised ways of describing processed modelling. Those methods of process modelling, such as OMEGA and EPK/ARIS, mainly were developed for describing business processes but they are commonly used for design processes as well. Especially the method SADT (i.e. Structured Analysis and Design Technique [11]) has gained importance in describing design processes. As well network techniques (e.g. CPM, MPM, or PERT) or bar charts are widely used for process planning, e.g. in project management. Figure 2 shows the process of developing a new, assembly optimised cutting device for a can opener that was planned and modelled by SADT [11]. The process elements are described in a unitised manner by input and output variables, an executed activity as well as other influencing factors such as supporting tools, involved persons, or any controlling variables (e.g. requirements). The activities are connected by arrows which link a certain output with an input.

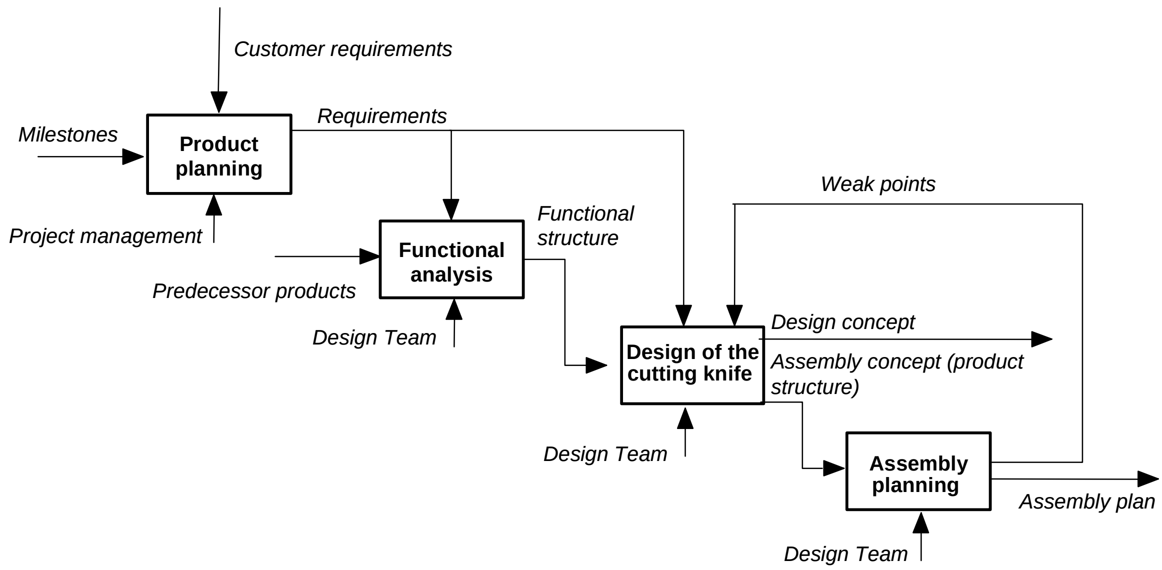


Figure 2. Process planning with SADT (example: design of a cutting knife, [5])

Most of the process modelling methods are applied to describe respectively to design a process in a normative way, e.g. as process guideline. Here, workflow management systems are widely used which automatically provide a predefined procedure and allocate necessary resources and needed information. As well, the process modelling methods can be used to analyse and redesign existing processes. Bottlenecks, queues, and critical paths can be identified and eliminated by mathematical algorithms, which lay behind the process models. Of course the modelling methods can also be utilised to plan new projects or design processes, e.g. in case of design changes due to specific customer requirements. However, most process modelling methods do not provide a sophisticated planning methodology themselves, rather the process planning goes hand in hand with drawing the process line.

Hence, the prevalent way of process planning is very path oriented, that means process inputs and outputs are just linked together as they fit best. Especially the conception or selection of necessary activities is not supported methodologically.

On the other hand, mainly in project management the planning of activities is based on a defined product structure which determines the project structure as well.

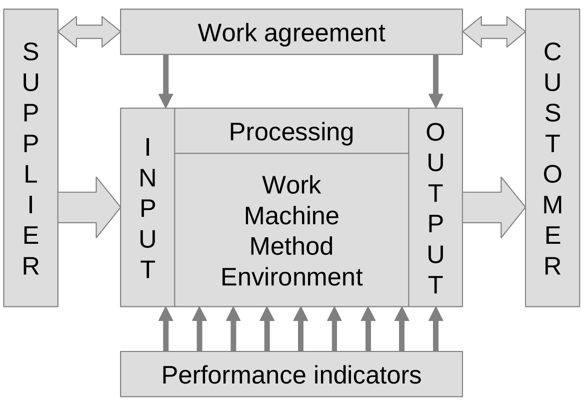
There are other approaches, e.g. in change management, where parameters of the product structure (e.g. a certain design parameter) and process paths are linked together [8]. Here, a detailed pre-planning of the required change processes is necessary. This might not be suitable as individualised products are concerned, where late changes occur far more frequently as in "normal" change processes.

Last but not least process planning (especially with respect to the selection of certain design methods) often bases on situational circumstances, e.g. whether a required competency or resource is available. Situational process planning is supported by method models [9] as well as method data bases [12] where necessary conditions for application are described for each method.

Especially a process planning on the basis of the existing product structure might be a suitable approach for a requirement oriented process planning. For that purpose it is necessary to bring requirement definition, process modelling and product structuring methods together in an integrated view.

Configuration of design processes

Some process modelling methods base upon the use of so called process modules [5, 13]. Not only these process modules have a predefined standardised structure (as is shown in figure 3) they can also be utilised for planning processes in a configuration like manner.



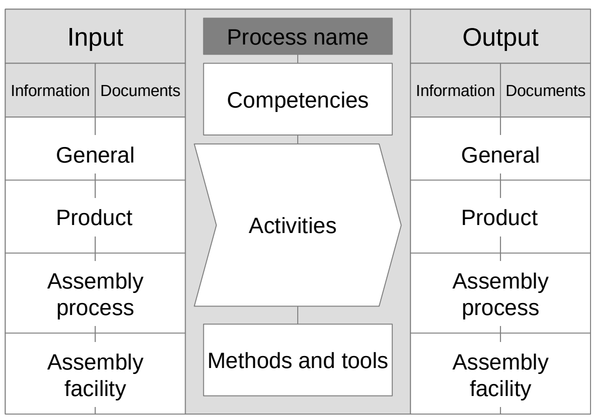


Figure 3. Process module [5] and process building block [13]

Configuration mainly bases on the idea of modularisation where predefined modules are reused [14]. Configuration systems can be seen as an appropriate measure to reduce complexity of markets, products, and processes. Every configuration system consists of (predefined) modules which are linked together according to a defined combination rule [15]. The modules are stored in a configuration base. The selection of modules from the configuration base during the configuration process can be supported by a decision system. Here, rule or knowledge based expert systems can be applied [15]. While rule based systems compare object oriented user inputs with the existing data base successively, knowledge based systems look at the given requirements and select suitable modules on the basis of these requirements. As well, every configuration system should have some kind of validity check, where the consistency of the configuration and the fit between original requirements and resulting configuration are proved.
The idea of configuration can also be utilised for a process planning methodology. As shown in figure 4 process modules can be selected from a process data base and linked together to an entire process plan. This idea was originally described by Bichelmaier [5], but he left open how to plan single process steps (modules) exactly and how to select them according to given requirements. Rather he has proposed a database of defined, SADT-based process module, so called process building block. This might hardly work when a flexible planning of individual change and design processes is required. Here, the spectrum of possible processes is open and cannot be planned completely on the basis of predefined process modules. Thus, it is necessary to provide a more flexible process planning methodology which allows the synthesis of new process modules on the basis of given requirements. As well, appropriate ways to realise a requirement oriented process selection and adaptation in a configuration-like manner are needed. An approach for that shall be, at least partially, described in the following section.

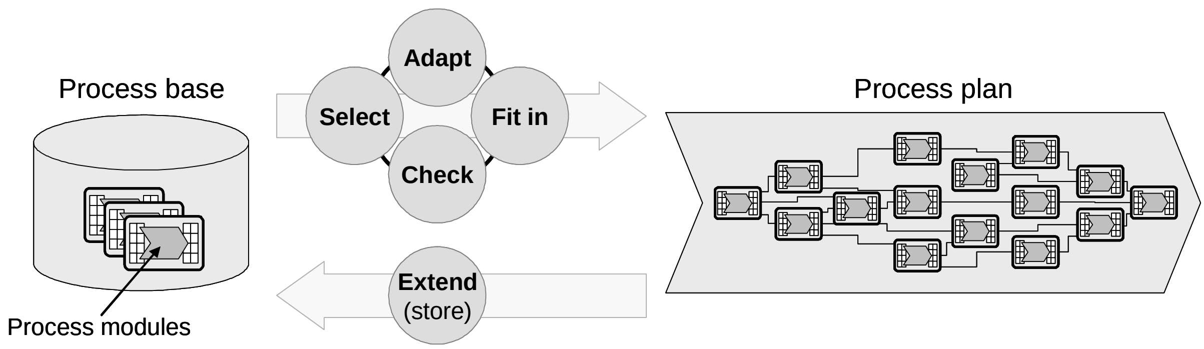


Figure 4. Process configuration (according to [5])

Requirement oriented process planning

To enable a flexible process planning methodology, two key aspects have to be regarded. Those are the requirement-oriented synthesis of adaptation processes and the configuration of processes in terms of reusing existing process modules. The synthesis of process modules on the basis of actual requirements is not supported by process oriented methods so far. However, product changes due to individual costumer requirements are frequent in special engineering or mass customisation and the respective design processes have to be planned systematically. As shown in the sections before these processes cannot completely be planned in advance (e.g. by using probabilistic decision networks or predefined process modules) because there are manifold and partially unpredictable customer requirements, which cause equally manifold adaptation processes. For this reason there is a need for a more “heuristic” process planning methodology. But before describing this methodology in detail, the parameters shaping a requirement oriented design process shall be clarified.

Parameters of a requirement oriented design process

Needless to say, the design requirements have a very strong influence on the design process. Beside internal and external boundary conditions of the design process they mainly determine which activities have to be executed (see also figure 1). Since, at least finally, components and parts of the products have to fulfil these requirements it is also possible in most cases to determine which requirements "belong" to which components [16]. And because each activity is bound to a certain component, the components which are affected by a requirement are an important parameter of a requirement oriented design process.

The components of a product can be described within the product structure. It is well known that product and process structure are intrinsically tied to each other [8, 16]. This especially applies for individualised products. Within the product structure of an individualised product it is also defined which degree of individualisation is possible for each element of the product [3]. This degree of individualisation strongly determines which adaptation process have to be expected. In figure 5 a model of the product structure of an individualised product is shown, which distinguishes several degrees of individualisation. Each component or even single parameters of the components can be described by that model concept.

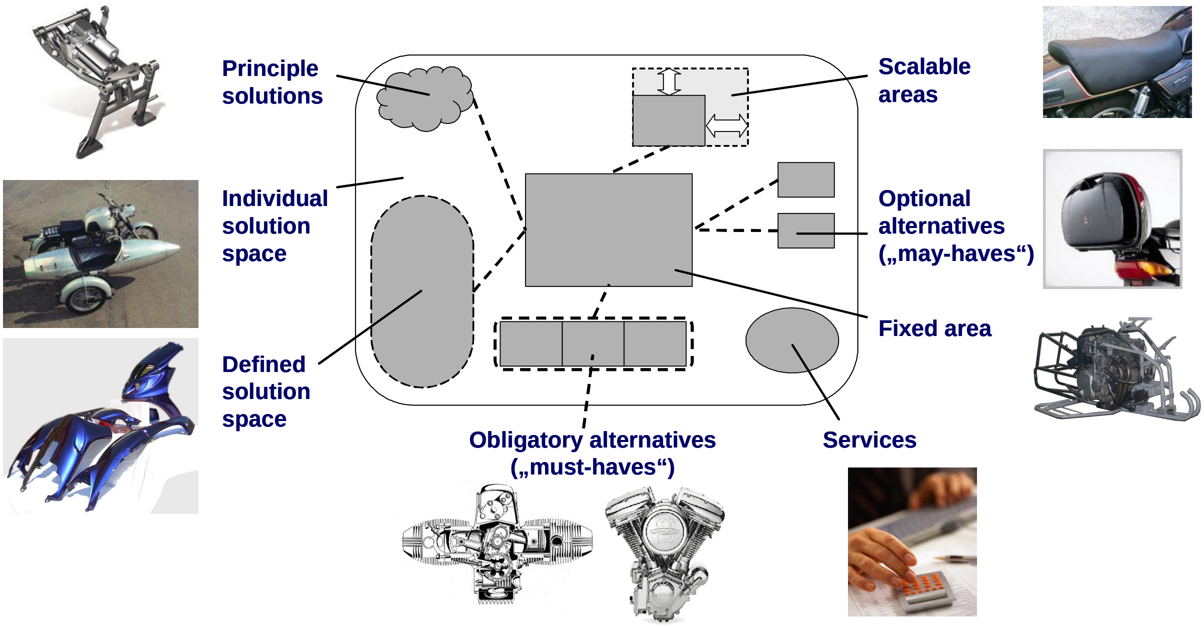


Figure 5. Structural concept of an individualized product [3]

Within the product structure of an individualised product several areas of individualisation can be distinguished: Most individualised products have a so called *fixed area* (e.g. a basic frame), where no individual adaptations are allowed. Accordingly it will not be necessary to plan any individual adaptation processes. The product structure of an individualised product also contains *obligatory or optional alternatives* which are already known from conventional variant products. One out of the obligatory alternatives has to be selected (e.g. a certain kind of engine) while optional alternative are not essential for the functionality of the product (e.g. accessories). In most cases no adaptation processes are necessary because the alternative components are predefined. However, it could be possible that an existing component has to be slightly changed or that a new alternative has to be developed according to customer requirements. *Scalable components* are eminently important for an individual adaptation of the product. Here, the design parameters to be adapted are predefined (e.g. an ergonomic adaptation of a seat or a handle) and therefore the adaptation process is predetermined as well. For some components the final design is not defined completely (especially on the design level) until the customer specifications are present. On the basis of a *concept or principle solution* the design of the component is finished. Especially, that applies for components which are widely used but might have a different design in each case (e.g. a certain connecting piece or the stand in the example in fig. 5). Again the adaptation process is quite predetermined. For unexpected customer requirements *solution spaces* can be defined within the product structure where a more extensive adaptation is possible. In some cases the components can be predetermined, where such extensive individual adaptation might be necessary more frequently (e.g. the casing). The product structure can be optimised for frequent adaptations at these components (so called defined solution space [3]). There are also individual solution spaces which are not defined intentionally but which exist within the product structure. Here individual product adaptations are possible although they were not planned before (e.g. an additional sidecar in fig. 5). However, the kind of adaptation cannot be planned in advance in both cases and so the adaptation processes cannot either. *Services* (e.g. a financing or maintaining service) complement the product individualisation but are not regarded here.

When planning individual adaptation processes, it is not only important which components of the product are affected by a certain requirement and which degree of individualisation is intended for these components respectively. It is also important what design level the requirement is referring to. According to engineering design methodology individual requirements might refer to the functional, physical, structural or part design level of a product or a certain component [6]. E.g., if an additional function is required by the customer the functional level and all subordinated design levels are affected. If only the dimension or the shape of a certain part have to be adapted according the part design level is affected but the functional level is not. Therefore, the design levels affected by an individual requirement determine the extent to which adaptation processes are necessary.

As shown in the section before it has to be considered which structural area and which design level is affected by an individual requirement in order to plan the respective adaptation processes. How these processes can be planned on the basis of the given requirements, the affected design levels, and the affected components and their status within the product structure will be shown in the following section.

Relation oriented requirement analysis and process synthesis

To support a requirement oriented process synthesis a method was conceived which bases on the relations between the specific customer requirements and the components within the product structure of an individualised product (figure 6).

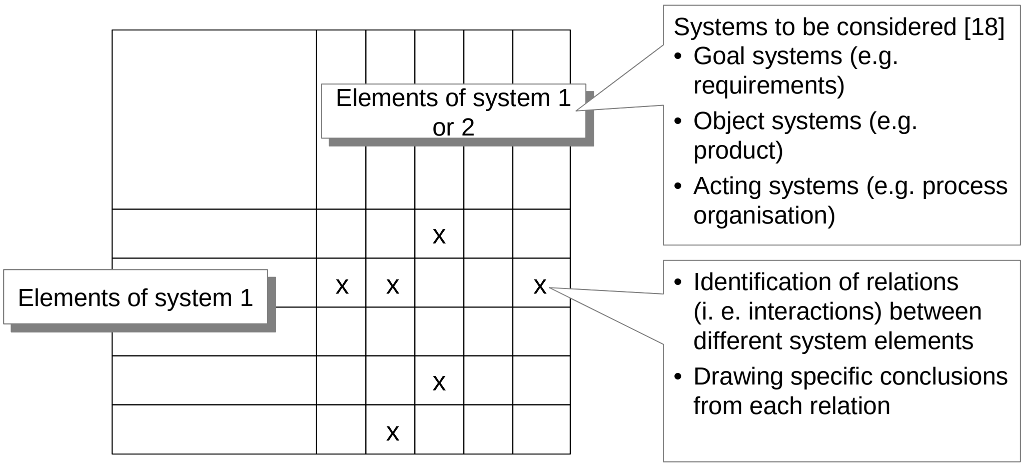


Figure 6. Systems analysis by Design Structure/Domain Mapping Matrix

This proceeding is similar to existing methods, such as Quality Function Deployment or Axiomatic Design [16], and it was also utilised by Jung [17] to identify requirements which are caused by relations between two system elements. According to that approach, possible individual adaptation processes might result from the relations between single customer requirements and product components.

The analysis of these relations can be supported by a Design Structure Matrix (respectively Domain Mapping Matrix if two different systems are regarded). By these methods relations between different system elements (e.g. requirements or components) can be visualised. If there is a relation between two elements further conclusions might be possible. E.g. two components show a relation because they influence each other by mechanical vibration. From that relation the requirement to damp the vibration or not to exceed a defined frequency might be derived. This basic approach can also be utilised to

- Identify requirements by an individual system analysis (A) and
- Plan individual adaptation processes on the basis of given requirements and linking them to corresponding components of the product structure (B, see figure 7).

To identify individual requirements, the individual user, its environment and its relation to the product have to be regarded. Individual requirements can be identified by looking at each relation and asking whether there are any special functional, design, quality, or other requirements in this relationship.

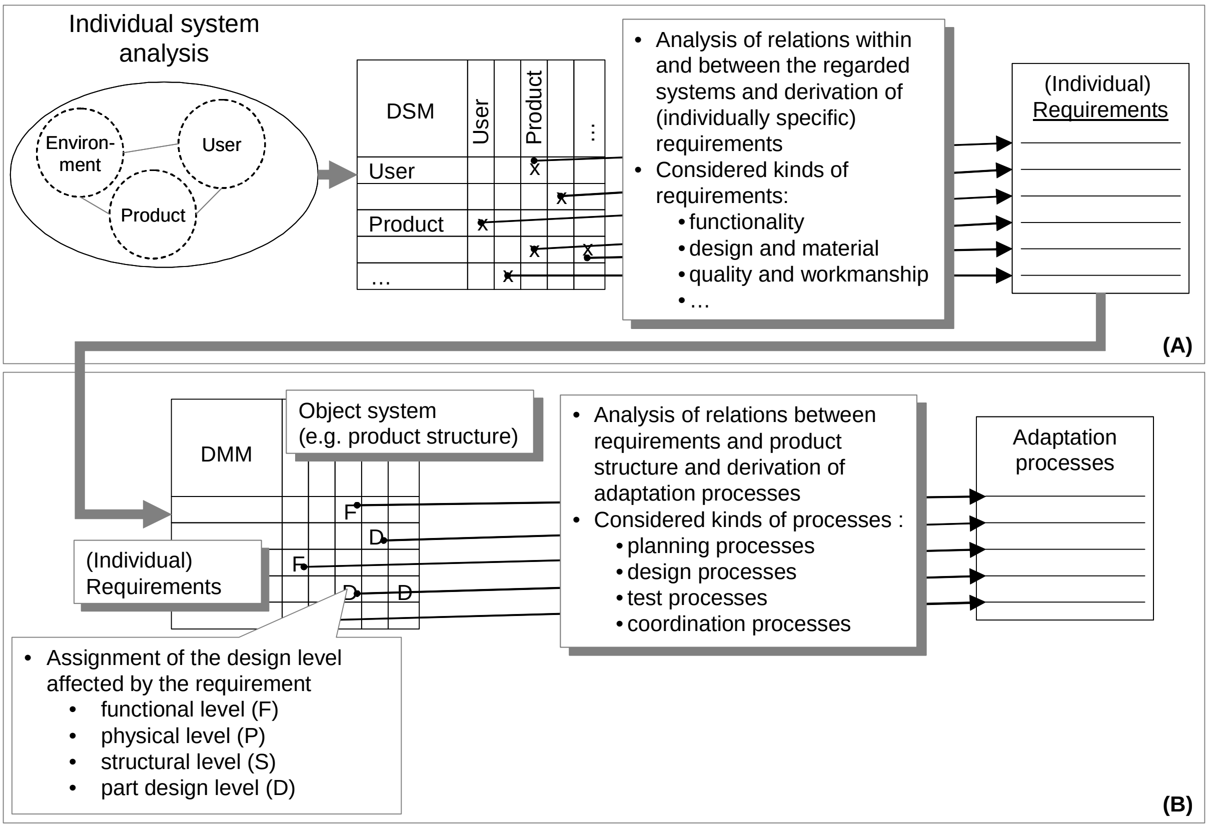


Figure 7. Relation oriented requirement analysis and process synthesis

To reason necessary adaptation processes, the individual requirements have to be linked to the components of the product which are affected by the requirements respectively. Again the identified relations between requirements and product structure are analysed. At each relation it has to be asked whether there are any planning, design, test, or coordination processes necessary in the context of the regarded requirement and the affected component of the product structure . As well, it has to be determined whether the functional, physical, structural, or part design level of the product/component is affected by the requirement because this is characterising the kind of relation between requirement and product structure. As a result of the relational analysis a list of necessary adaptation processes can be derived. The single adaptation processes have to be described in a standardised manner to support the configuration and the reuse of process modules.

Requirement oriented configuration of design processes

To describe the synthesised processes in a formal, standardised manner, process modules as shown above might be used. By a process module the process input and output as well as the related activities and methods are defined [5]. Beyond that, the process parameters which were determining the adaptation process should be added to the process definition. As explained in the section before that are the individual requirement itself, the affected design level, and the affected product element (see also figure 8). As well, the kind of requirement and the kind of adaptation process should be described to characterise the process module more generally. By this characterisation, the reuse of process modules shall be supported. The most suitable process modules can be identified for reuse. For that it is necessary to store the process modules in a configuration base from where they can be selected and put together in a new process configuration. If this configuration base contains a good amount of process modules it might be unnecessary to synthesise new rather than to adapt existing processes.

Case example

In the following section the application of the method shall be described in a short case example at a manufacturer of packaging machines. Here the new function "C" should be implemented. The case example is illustrated in figure 8.

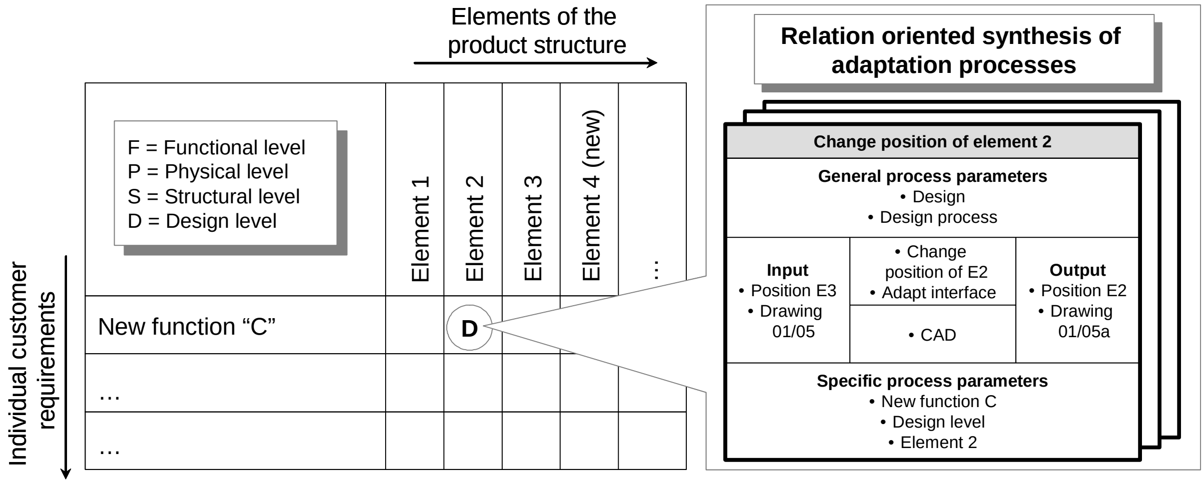


Figure 8. Case example

Element 2 were affected by that requirement on the design level while element 4 had to be developed originally. Several adaptation processes were concluded from the relation between the requirement of the new function "C" and element 2. E.g. the design process "Change position of element 2" was defined. Inputs and outputs as well as necessary process activities were described by a standardised process module. This process module can be stored in a database. From there it can be selected and adapted if similar process conditions occur in future again. The described process parameters, such as the requirement ("new function") and the affected element of the product structure ("element 2") then might help to find this process module again and to reuse it accordingly.

Conclusions

The introduced method supports the flexible and rapid planning of individual adaptation processes. This is necessary to respond to individual product requirements appropriately. As opposed to existing methods of process development the method does not focus on the description of processes from an analytical view but rather shall enable the synthesis and configuration of individual process chains. The approach of utilising relations between requirements and the elements of the product structure has proved to work well and supports a systematic process planning. As well, existing methods of process modelling were adapted to support a standardized definition of the processes. For this, process modules are described by additional parameters which shall enable an extensive reuse of already defined process modules. In future, the identification and selection of process modules shall be computer-aided. Especially knowledge based configuration systems might help at this. E.g., the retrieval of processes from a configuration base can be supported by expert methods such as Case Based Reasoning [4]. Again, the systematic description of process modules is a prerequisite for applying these expert methods.

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