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SUITABLE METHODS FOR PROCESS MODELING AND PROCESS OPTIMIZATION

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ABSTRACT

The current situation in product development is characterized by increasingly dynamic and complex tasks. The development of a product is not a linear process, continuously guided by well-defined steps to the target. Few products are newly designed; most are adaptations, modifications, or variant designs. However, there is a common requirement for each case when the processes have to be deposited for the first time in a process management tool: that it must be done quickly and relatively easily. Various modeling techniques and languages exist: among them network diagrams (e.g. flowchart representation as Business Process Model and Notation (BPMN)), container modeling and Design Structure Matrix (DSM). These process modeling methods are brought together into the Tri-Process-Modeling-Tool described in this paper. The benefit of each process modeling method is shown, together with the main tasks associated with it. Furthermore, it is demonstrated that the application of those different process modeling methods is also useful for process optimization.

Keywords: design process, optimization, process modeling, simultaneous engineering, degree of parallelization

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1 INTRODUCTION

For effective product development it is necessary to monitor and control all the processes and activities involved. Processes in product development are usually very dynamic, because innovation and creativity do not follow a strictly defined path. In order to obtain a common understanding of some of the terms used in this paper, they are predefined as follows:

- A **process** consists of interrelated activities or sub-processes for performing a task. The number of activities is not limited in their length and duration. The compounds of the activities or sub-processes are not rigid. Thereby a sub-process is the subset of a process and also a set of activities or other sub-processes ((Hammer and Champy, 1993), (Hammer and Champy, 1995), (Freisleben, 2001), (Schabacker, 2001)).
- A project is a living process (or several connected ones), in which boundary conditions are defined and which is always unique (DIN 69901).
- A **process element** describes an activity, operation or one or more working steps respectively, and is initiated by one or more events and ends in one or more events. The individual process elements are closed in content and relate to each other in a logical context. The description is made on the basis of a defined structure, so that they are also suitable for use in computer-aided systems (Freisleben, 2001).
- A **process model** is a procedure model based on the description and modeling in the form of processes for efficient treatment of scopes of tasks which are composed of a variety of interrelated or interactive single activities (Motyel, 2006).

One can distinguish between different types of processes. In Table 1 the main differences between processes in production and product development are shown. Processes in product development are neither predictable nor readily completely reproducible. Additionally, it is difficult to control objectives, durations, resources and costs of a project in this environment. Thus, these processes are fundamentally different from those of manufacturing, sales, administration, and controlling (Table 1) (Vajna et al., 2002).

Table 1. Differences of Processes in Companies (Vajna et al., 2002)

Processes in manufacturing, controlling, administration	**Processes in product development (engineering processes)**
Processes are fixed, rigid, reproducible to 100%, and reviewable.	Processes are dynamic, creative, chaotic; many loops and jumps.
Results must be predictable.	Results are not always predictable.
Material, technologies and tools are physically available in manufacturing and described completely.	Defined objects, concepts, ideas, designs, approaches, trials (and errors) are virtual and often not precise.
Probability for disturbances is low, because objects and environments are described precisely.	Probability for disturbances is high because of faulty definitions and desire for change (requirements).
Dynamic reaction ability is not necessary.	Dynamic reaction ability is necessary.
⇒ **Process control**	⇒ **Process Navigation** ⇒ **Project Navigation**

Figure 1 shows dynamic project navigation with the help of three levels which are implemented in different modules of the project navigation tool *proNavigator*:

- **Planning level**: The user captures and models processes with the module *proModeller* using predefined process elements. The module *proReviewer* simulates the affiliated processes with specified iteration number and alternative paths and provides information about the expected benefit-return, an estimation of the associated risks and an overview of the potential benefits, together with their probability distribution. If necessary, the recorded processes are optimized and improved alternatives are generated.
- **Reference level**: The module *proManager* provides the integrated user interface that coordinates all the activities of the modules of the proNavigator.
- **Execution Level**: The simulated processes are carried out as projects in the respective project

management software. If disturbances occur, the project will be stopped and a dynamic synchronization will be performed, i.e. the project will be returned as a process to the planning level, simulated again and put back into the project management software. During a project the project participants have access to the attached process documentation and description in the module *proBrowser*.

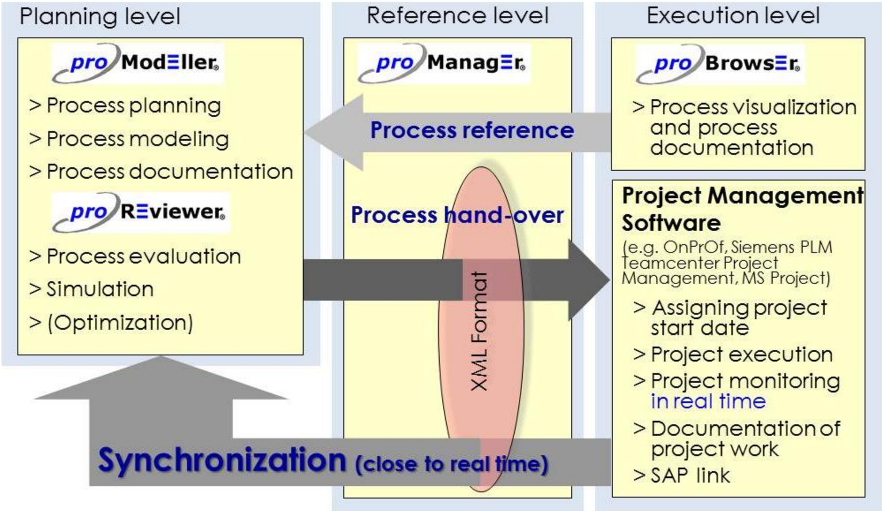


Figure 1.Dynamic Project Navigation

It must be noted that the creation and maintenance of process models require considerable effort. For this reason a sense of proportion is advisable in process modeling rather than a highly detailed approach.

2 THE TRI-PROCESS-MODELING-TOOL

While developing the appropriate modeling method it has to be kept in mind that the process modeling tool should meet all the requirements, allow different views for modeling and, at the same time, combine the advantages of the modeling method. This cannot be done within a rigid schedule, because such approaches are not capable of reacting to unforeseen disturbances and changes flexibly and dynamically. The process model should be able to respond to changing variables in real time and show the necessary alternatives (Vajna et al., 2002).

2.1 Concept of Tri-Process-Modeling-Tool

For writing and presenting the product development processes, there are several ways to model processes. The selection of the appropriate method(s) or combination of methods whose properties complement each other perfectly for process modeling is discussed in the article (Szélig et al., 2012). Here, three methods were selected whose benefits are summed up in a tool.
The result is the Tri-Process-Modeling-Tool (Figure 2), in which a diagram with BPMN symbols (Business Process Modeling and Notation), a container model and a DSM (Design Structure Matrix) are merged into a Tri-Process-Modeling-Tool. As it has two more modeling representations, this tool should replace the module *proModeller* in which only Container Modeling is achieved.

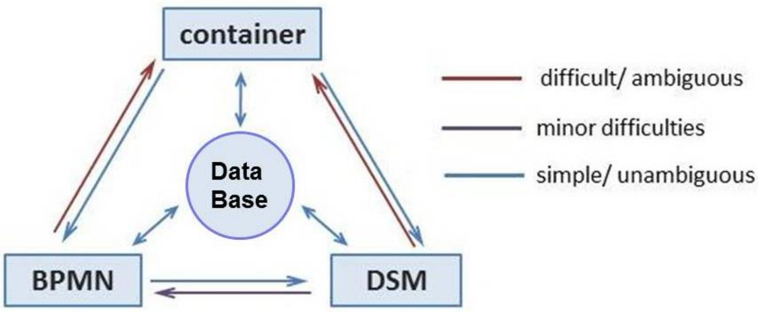


Figure 2. Interfaces between the three representations of the process model

2.2 Modeling with the Tri-Process-Modeling-Tool

In order to model product development processes, it is first necessary to analyze the actual situation and consult persons involved. To facilitate and support this process modeling, predefined elements are used also (Figure 3).

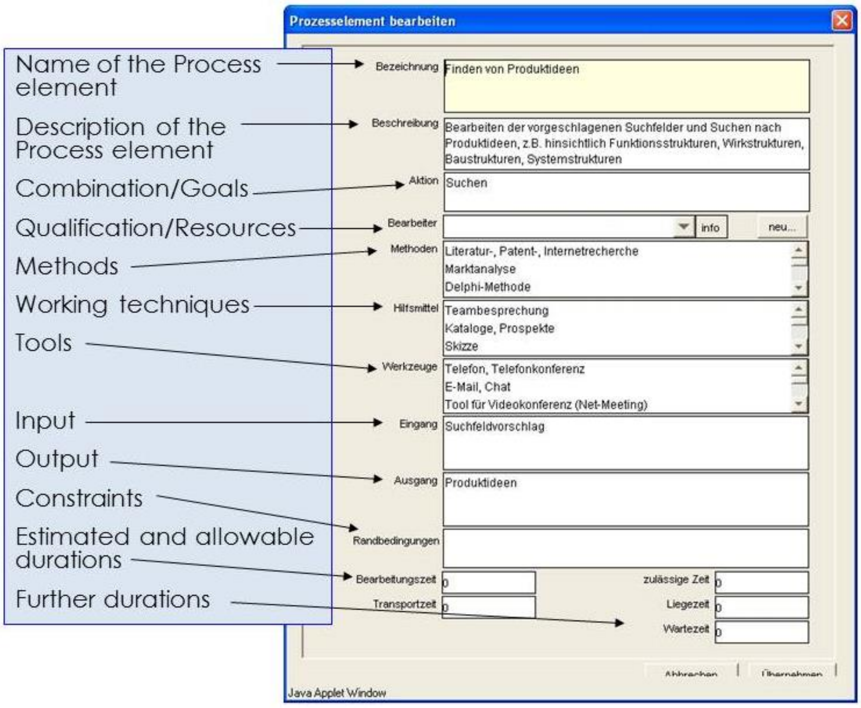


Figure 3. Inputs for a single Process Element

The process can be captured in a graphic diagram representation of the BPMN 2.0 standard (eg in (Freund and Rücker, 2010), (Palluch and Wentzel, 2012)). BPMN provides not only arrow-connected activity elements, but also sub-process icon elements that can be expanded from or reduced to higher-level elements.

The BPMN diagram (Figure 4) is a process node network with a variety of gateways, allowing branches in parallel or alternative processes.

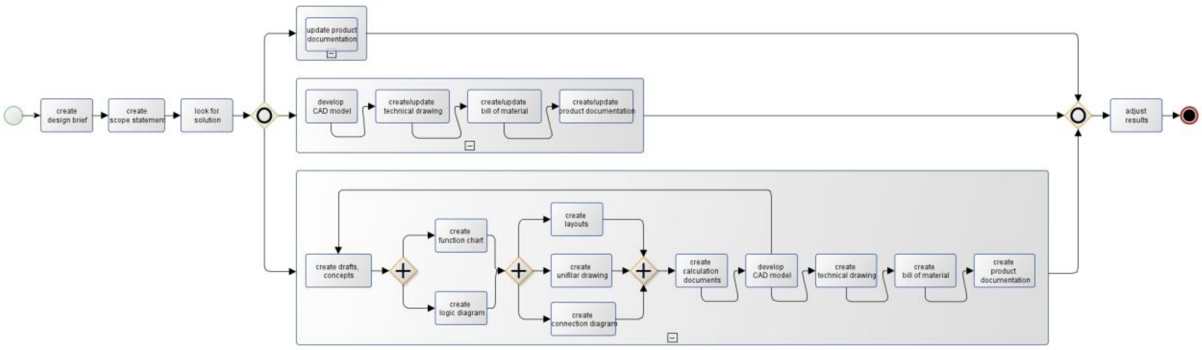


Figure 4. Diagram in BPMN representation

The notation uses standardized symbols of the BPMN. This graphic description scheme also allows the representation of stochastic procedures. For modeling, the three gateways (data-based exclusive gateway (XOR), inclusive gateway (OR), and parallel gateway (AND)) may be utilized, with the help of which the alternatives and parallel elements can be represented. In an exclusive gateway only one alternative can occur, which excludes the other. The gateway can be of a branching or composing type. The inclusive gateway can describe an and-or-situation in which either one, several or even all outgoing paths may proceed simultaneously. The combined effect will be reused where the paths converge again. Some actions do not necessarily need the completion of previous actions, but can be performed simultaneously with one or more other actions. For this purpose the parallel gateway may

be used, which operates both parallelizing and synchronizing. Parallelization does not mean that the tasks must necessarily be performed simultaneously.
For a consistency check the container representation can be used in which the iterative and alternative subprocesses are clearly visible and the filling of the container with the associated data is possible.
The principle of Container Modeling according to the IDEF0 (International DEFinition Language 0) standard (e.g. in (Marca and McGowan, 1988), (Freisleben, 2001), (Kim et al., 2001)) depicts that the sequential, parallel, iterative or alternative (sub-) processes may form a group, the so-called container. To these containers can be added process activities, together with the corresponding process-relevant data and information. The containers can in turn contain other containers or be contained in other, larger, containers (Figure 5). Frequently used container constructs can be stored in a sub-process library and reused at any time, at any point in any process model.

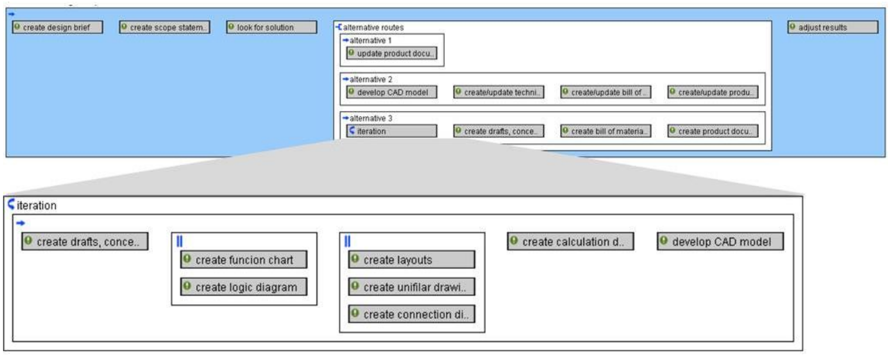


Figure 5. Container representation of sample process

From experience it has been found that on the one hand Container Modeling provides a very well-structured process representation, while on the other it is difficult to be handled by the user during the process deposition step.
During the modeling process the number of possible iteration steps and the most likely path of process alternatives are not determined, either in Container Modeling or in BPMN modeling. This first occurs in a process simulation, when the processing time and the costs of the process are to be determined. If the conclusion of a process simulation is that the process structure should be optimized, it is very difficult to break these structures in container and BPMN representation. Thus an intermediate step is required to simplify this breaking up process. This is done by using the DSM ((Rick, 2007), (Lindemann et al., 2009)), which defines and maps the relations of the single process elements with full precision (Figure 6). It treats the cycles and feedbacks clearly and simply. With an extension it is possible to model the alternatives in the process.

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	R	S	T	O
A	create design brief		1																		
B	create scope statement			1																	
C	look for solution				1/3	1/3				1/3											
D	update product documentation																				1/3
E	develop CAD model						1														
F	create/update technical drawing							1													
G	create/update bill of material								1												
H	create/update product documentation																				1/3
I	create drafts, concepts										1	1									
J	create logic diagram												1	1	1						
K	create function chart												1	1	1						
L	create layouts															1					
M	create unifilar drawing															1					
N	create connection diagram															1					
O	create calculation documents																1				
P	develop CAD model									2								1			
R	create technical drawing																		1		
S	create bill of material																			1	
T	create product documentation																				1/3
O	adjust results																				

Figure 6. Extended DSM

In the DSM all alternatives are listed. These are represented as a fractional number. With three alternatives the value 1/3 may be possible. This value is not related to the likelihood of the alternatives. The active alternatives are treated later, as are the parallel elements.

The transition between the three representations is associative. It is possible to enter the process data in any representations, which is then converted to other representations. Each of the three representations has its advantages and disadvantages. It is not possible to create all process information in all the representations equally well. This is why the Tri-Process-Modeling-Tool is used, to make it possible to treat all information in the currently best representation and to estimate and optimize the time and resource requirements of the process.

Table 2 shows the most appropriate main tasks for the particular process modeling methods.

Table 2. Methods and their main tasks in the Tri-Process-Modeling-Tool

Process modeling methods	Associated main tasks
BPMN	Planning and modeling of the processes
Container Model	Checking the consistency of the processes
DSM	Exact representation of the iterative and alterative paths

An optimization of processes by different priorities should be possible, for example by duration, the qualifications of the available persons in charge, costs or the maximum exploitation of a particular tool (Vajna et al., 2002).

With graphical representation such as BPMN, the process structure is modeled intuitively by using arrow connections. However, the sub-process structures are difficult to survey in this representation mode, especially in the case of parallel structures. This drawback is countered by Container Modeling (a container includes a serial, parallel, iterative, or alternative process structure), which provides clear visibility with respect to process results present when leaving the container. However, this modeling technique does have the weakness that, for iterative or alternative procedures, additional containers must be defined in order to know whether serial, parallel, iterative, or alternative process structures are included. The representation of iterative processes in BPMN may be very confusing and ambiguous, because especially for nested, iterative processes the beginning of an iterative sub-process can hardly be seen. DSM in turn counters this disadvantage, as with DSM the relations between the elements are unambiguously specified and a clear process structure can be obtained. It is not expected that the elements are immediately written in the correct order (from the perspective of time, resources, and costs). The advantage here of DSM is that the reorganization of the process elements is possible in order to satisfy time, resources, and cost targets.

3 PROCESS OPTIMIZATION OF PRODUCT DEVELOPMENT PROJECTS

After modeling a process, the following optimizations of the process may be initiated (Figure 7) (Schabacker and Vajna, 2003):

- **Qualification Balancing**: In the first step specifically qualified personnel are assigned to the process elements. In the second step, existing methods, approaches, and tools are replaced by the most appropriate version by employing the BAPM (Benefit Asset Pricing Model) method ((Schabacker, 2001), (Schabacker, 2002), (Schabacker and Wohlbold, 2002), (Schabacker, 2010)).
- **Simultaneous Engineering**: The output data of process elements are compared with the input data of follow-up process elements with the aid of the degree of fulfillment (Figure 8 and example below). If the conditions of the degree of fulfillment are met, matching process elements are linked together, so that several different process elements can be (at least partially) processed in parallel. Additionally, in this step waiting and idle periods of the individual process elements are cut to a minimum. A control variable here is the provision of the minimum information necessary for the parallel or follow-up process element to begin (Vajna et al., 2005).
- **Concurrent Engineering**: A process element is distributed to several parallel processing commissioners, whereas a clear definition of skills and (chronological and physical) interfaces between these has to be made in advance to maintain the consistency of the process element (Vajna et al., 2005).
- **Time Concentration**: In the sense of a maximal shortened project processing duration, the

entire process topology of the project is restructured (reconfiguration) with the aid of evolutionary methods (similar to the optimization of products, such as in (Vajna et al., 2005) and (Vajna et al., 2011)). Results may include, for instance, modified processing sequences and further parallelization of the process elements.

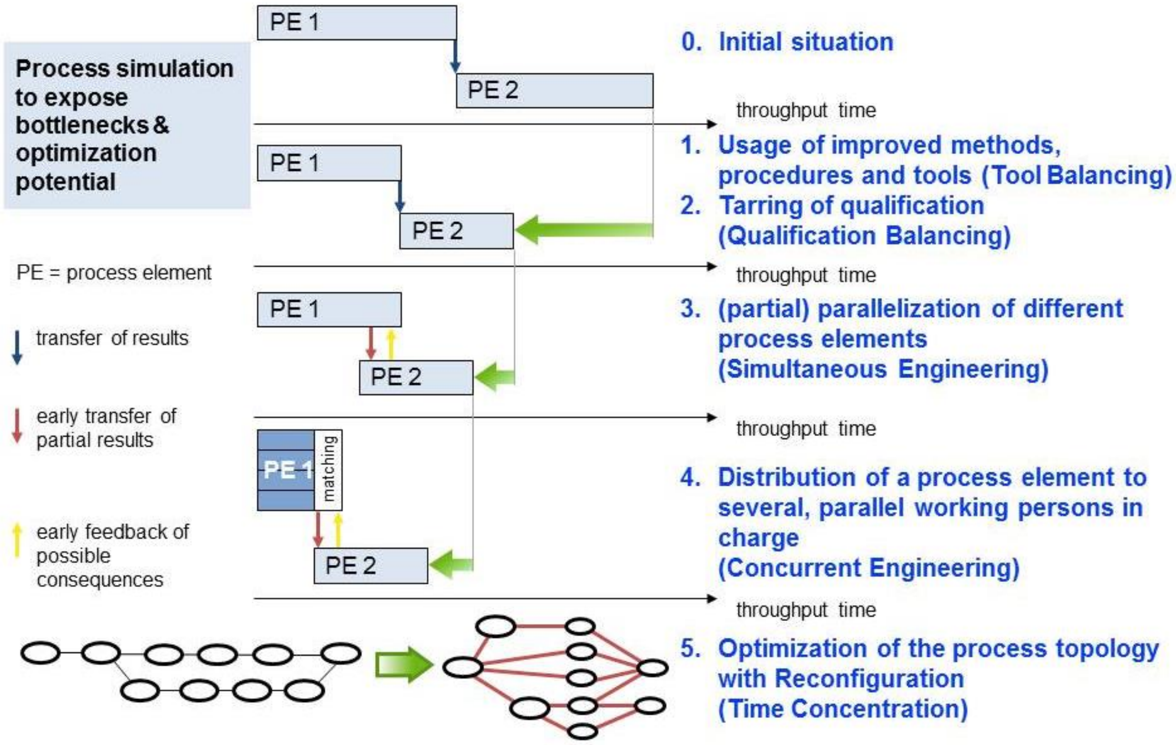


Figure 7. Stages of process optimization (Schabacker and Vajna, 2003)

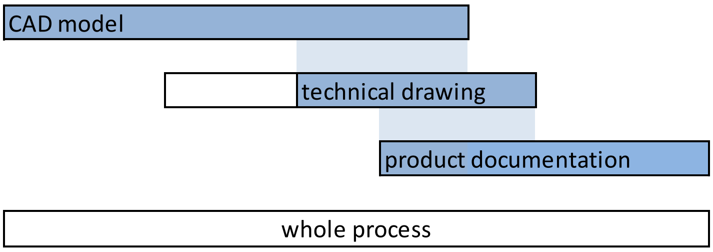
For the optimization stages of *Simultaneous Engineering* and *Concurrent Engineering* it has to be determined what percentage of a process element needs to be completed in order to start the next process elements. This can be done reasonably with the use of the documents that will be created, such as CAD models, technical drawings, and product documentation (Schabacker et al., 2002). The degree of fulfillment needed for parallelizing process elements is thus measured by the partial completion of documents. Consequently, document types will be defined.

Depending on the process and the company, the extent of overlap among process elements and thus the degree of fulfillment for parallelizing process elements may vary. For simultaneous elements a lower limit for the time advance must be introduced, with which the earlier element is completed before the later element (called minimum time advance), to ensure that the later element, which depends on the information of the earlier element, has enough time to run. Surveys can determine the percentage.

If multiple documents are created in a single process element and a premature beginning of a document within a process element is possible, it is useful to divide the process element into sub-process elements (Concurrent Engineering), where each sub-process element contains exactly one document, and therefore multiple commissioners can work on different documents and sub-process elements in parallel.

The lower limit of the degree of fulfillment provides the highest parallelization, along with the highest risk. In this case, it may happen that the element needs to be divided into several parts, to ensure that the minimum termination condition is satisfied. If partial elements are undesirable, the degree of parallelization is obtained by a comparison of the weighted difference between the degree of fulfillment and element length (100%) with the weighted difference between the minimum termination and the length of the next element. The lesser of these two differences is the degree of parallelization between two elements. The degree of parallelization in the overall process is the sum of the individual parallelizations. Standardization is already taking place through the individual weightings, the sum of which is always exactly one.

Example: In a process element, the three documents - a CAD model, the technical drawing, and the product documentation - are created. Of course, a CAD model doesn't need to be 100% completed in order to derive the technical drawing or begin product documentation. Perhaps the product documentation can be performed in parallel with the technical drawing. Furthermore, the project manager will be able to select the best possible qualification profile for all three documents separately. Instead of assigning a design engineer to work on all three documents, the project manager can give the technical drawing to a draftsman, which under certain circumstances may lead to lower process costs, due to the lower hourly rate (Figure 8 and Equation 1, Equation 2).



degree of fulfillment	minimum time advance	weight (percentage of the total length)	degree of parallelization
e	m	s	p
30%	-	0.43	
			0.2
25%	20%	0.25	
			0.1875
-	35%	0.32	
			0.3875

Figure 8. Sample data for the calculation of the degree of parallelization

$$p_{process} = \sum_{i=1}^{n} \min\left[s_i(1-e_i); s_{i+1}(1-m_{i+1})\right] \quad (1)$$

$$\sum_{i=1}^{n} s_i = 1 \quad and \quad \sum_{i=1}^{n-1} p_i = p_{process} \quad (2)$$

In this example, the derivation of the technical drawing can be started at the earliest when the CAD model is 30% completed (degree of fulfillment – e_1). After the completion of the CAD model, the drawing takes at least 20% of the time (minimum time advance - m_2) to get ready. Only in special cases may these values be the limits according to the predetermined percentages, so that smaller overlaps must be taken. For this, the weight (percentage of the total length) of the individual elements is calculated: $s_1 = 0.43$ and $s_2 = 0.25$. For instance the largest possible overlap of element CAD models is s_1 (1-e_1) = 0.43 (1-0.3) = 0.301 and that of the element drawings is s_2 (1-m_2) = 0.25 (1-0.2) = 0.2. The minimum value is 0.2, which is the degree of parallelization p_1.

Boundary conditions:

- It is assumed that only the relation to the directly preceding element needs to be considered. In this example, Figure 8, the predecessors of the element *documentation* are the elements *drawings*, and *CAD models*. The documentation can only begin when both the drawings and the CAD models have achieved a certain degree of fulfillment. Nevertheless, only the degree of fulfillment of the drawings is considered and it is assumed that this already includes the degree of fulfillment of the CAD models with regard to the documentation.
- Furthermore, the splitting of elements is excluded. A premature start to an element is conceivable if it is interrupted as soon as new information is needed. However, here it is assumed that once begun, an element is executed continuously until the end, and cannot be broken into several parts.

4 SIMULTANEOUS MODELING IN A TRI-PROCESS-MODELING-TOOL

The time overlap of normally sequential workflows thus provides a bonus time and/or a shortened processing time, respectively. Once there has been sufficient information gathered in a workflow, the next workflow is started in parallel. This sometimes leads to more work, because it cannot always be operated with the final level of information, but the basis for work may change at any time.

For sequential process elements a time overlap is possible. A process element can be initiated before the previous item has been completed. The processing of the element can start with a certain amount of information delivered by the predecessor. Further data are supplied continuously. The predecessor must be ended earlier than the current element, so that all information can be adopted.

In the diagram representation, the arrows that do not begin at the end of the element but at a certain point (with given percentage) indicate that at this degree of fulfillment overlapping is possible (Figure 9). These arrows lead to the beginning of the next element. Additional arrows from the end of a predecessor to a point in the current element indicate where no further proceeding is possible without the final data.

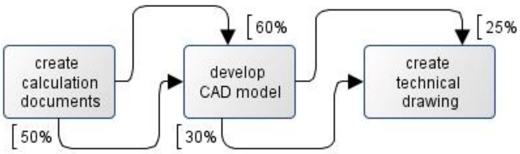


Figure 9. Representation of a simultaneous case

Table 3 shows which methods can be used to perform the particular stages of optimization and which process models are used to do so.

Table 3. Stage of optimization with corresponding methods and process models

Stage of optimization	Method	In which process model
Qualification Balancing	BAPM	Container Modeling
Simultaneous Engineering/ Concurrent Engineering	Parallelization method and extended DSM	DSM
Time Concentration	Evolutionary methods	DSM

5 SUMMARY AND OUTLOOK

With the modeling methods discussed above, the Tri-Process-Modeling-Tool combines the following benefits for a project manager:

- a flowchart representation for process planning, which is combined with BPMN
- a Container Modeling tool, which is useful for checking the consistency of a process and for the stage of optimization *Qualification Balancing* with BAPM and
- a DSM for time, cost, and risk forecasts, especially for iterative and alternative processes during the stage of optimization *Simultaneous Engineering* and *Concurrent Engineering*

Companies applying the optimization approaches discussed above will be able to perform better and create more efficient product development projects. The above mentioned assessment and optimization approaches allow the product development cycle times to be shortened, thereby reducing the cost of product development and improving the utilization of project participants in on-going product development projects.

The higher the degree of fulfillment to parallelize processes, the smaller is the expected value for the total duration of the process. At the same time the risk that this expectation is exceeded grows, i.e. the distribution deforms toward larger total process duration.

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