

A Process Standardization Approach to Enhance Design Verification

Sebastian Schweigert¹, Cristina Carro Saavedra², Nils-Jorge Marahrens³ and Udo Lindemann⁴

¹Institute of Product Development, Technical University of Munich, Boltzmannstraße 15, 85748 Garching, Germany. schweigert@pe.mw.tum.de

²Institute of Product Development, Technical University of Munich, Boltzmannstraße 15, 85748 Garching, Germany. carrosaavedra@pe.mw.tum.de

³Institute of Product Development, Technical University of Munich, Boltzmannstraße 15, 85748 Garching, Germany. nils_jorge@mytum.de

⁴Institute of Product Development, Technical University of Munich, Boltzmannstraße 15, 85748 Garching, Germany. lindemann@pe.mw.tum.de

A continuous implementation of verifications during the design process is currently not common praxis in the industry. Verifications of product requirements are realized, but only at certain predefined points of the process, causing iterations that can be redundant and extensively costly in some cases. However, applying verifications at a very detailed level is challenging for various reasons. Often definitions of relevant aspects for verifications like available inputs at a process step, available verification methods or the involved actors are missing. We propose process standardization as a way to bring transparency into the process. Therefore, we developed an approach to analyse the verification methods currently applied for each specific process step. Based on that, standard process configurations can be derived and new verification methods can be assigned. The approach combines the idea of the Stage-gate method from innovation management with a detailed analysis of process steps by an extension of the Business Process Model and Notation nomenclature for process visualization. The result is a profound verification of each step in the design process while maintaining necessary flexibility.

1. Introduction

The design process aims at creating reliable and efficient products that meet the requirements of customers under specified conditions. It can be divided into several phases: like 1) planning and task clarification, 2) conceptual design, 3) embodiment design, and 4) detail design (Pahl & Beitz 2007). Continuously verifying the degree of fulfilment of requirements of the designed product is essential to assure the target achievement of the design process. A verification can be defined as the "process of evaluating a system to determine whether the products of a given design phase satisfy the conditions imposed at the start of that phase" (Lake 1999). In case the output of a verification reveals that a design does not fulfil its requirements, the design must be reconsidered, leading to an iteration in the design process. The higher the amount of process steps carried out between verifications, the higher the impact of a potential iteration (Reinertsen 2009). While some of these iteration may not be avoidable, there are also redundant iterations in the development process that represent a potential for cost and time reduction (Ballard 2000).

Verifications are traditionally applied in the design process at so called "quality gates" at the end of main phases (Spath et al. 2001). This approach guarantees the goal of the design process (designing reliable and efficient products), but it is not sufficient to avoid iterations. Numerous iterations occur within the design phases and when failures are detected at the "quality gates". Thus, companies have the need to introduce verifications at more detailed levels and implement them continuously during all steps of the design process in order to reduce the number of iterations as far as possible and to identify necessary iterations early. However, applying verifications at a very detailed level is challenging for various reasons. One reason is that necessary inputs to conduct verifications are not always available (or completely

Paper submitted to:

R&D Management Conference 2016 *“From Science to Society: Innovation and Value Creation”* 3-6 July 2016, Cambridge, UK defined) before the end of the design phases, especially if they must be delivered from other departments. Another reason is that not all designers have the necessary knowledge to conduct verifications, particularly if verifications require special knowledge about modelling or simulation (D’Albert et al. 2015). Furthermore, it is usually not defined at which point of time verifications must be carried out and by whom.

One solution to these problems is process standardization focused on continuous application of verifications during design because proper process modelling is a prerequisite for adequate communication in complex engineering projects (Maier et al. 2011). Thus, the availability of inputs and of knowledge to perform the verifications can be synchronized with process activities and the involved actors and verification criteria can be clearly defined.

Within this paper, we propose an approach based on process standardization using the Stage-gate method as of (Cooper 1990) at the process step level visualized by an extended Business Process Model and Notation (BPMN) nomenclature. Within our approach, current methods for verification of every process step are analysed, then new configurations of the design process are proposed and new methods for verification are defined. The results are demonstrated by a case study with an industry partner. Due to the confidentiality agreement with the industry partner all values in the examples and the case study are only exemplary.

2. State of the Art

In the upcoming section we give a short recap on different process standardization approaches currently used. Thereby, a specific and detailed introduction to the Stage-gate method and its terminology will be given, which will serve as a basis for the approach considered in our work. Subsequently, we will give a short introduction into process modelling and visualization including the Business Process Model and Notation (BPMN) that we used as a basis for our process descriptions and analysis.

2.1 Process Standardization Approaches

There are several standardization approaches for product development in literature. Simultaneous Engineering (SE) is a systematic approach for the parallelization of development processes through time overlapping of development steps. Its focus is on improving the links between company entities and it requires considerations at a global level (Ehrlenspiel 2003, Weber 1999). A special focus is thereby given on the early design stage so that requirements are properly formulated, which enable a parallel working process structure. If SE is applied correctly, a time reduction for the entire development process of up to 42% and 20% cost reduction are possible. On the downside, SE bears the risk of a faulty product when time pressure is too high and its success highly depends on the qualification of the team leader (Ehrlenspiel 2003). Another term that is often used synonymously for Simultaneous Engineering is Concurrent Engineering.

Lean development is a philosophy based on eliminating waste of time and resources and focuses specifically on value creation for the actual product. Lean ideas emerged as an entrepreneurial concept in Japan in the 1950s to improve the production (lean production) (Oppenheim 2004). A special emphasis in lean philosophy is put on avoiding waste in the transformation of information for instance by standardization, which is supposed to secure improvements in the process (Erlach 2010, Oehmen and Rebentisch 2010). Thereby, its major focus is strategic and it requires a global understanding of the company (Oppenheim 2004). The lean methodology also includes its own modelling notation, the value-stream map, which makes it possible to display a process, the relations between different process-entities as well as pulse-lengths for different process steps. Subsequently, this information is used to perform a value-stream design, where waste is reduced and the pulse times for each process step are redesigned to result in a process flow that is pulled by its outputs (Erlach 2010).

The Stage-gate method, which originates from the field of innovation management, proposes to model product development based on realization steps (stages) and output verification (gates) (Cooper 1990). It is a standard normative approach that combines recommended actions in a process model (Verworn and Herstatt, 2000). In Cooper 2007 the concept of Stage-gate is already transferred to technology development projects that naturally deal with a high-risk of success and the need for intense quality assessments. Thereby, the systematic assessment of different solutions at the gates enables a comparison between different technological solutions and promises to increase decision process transparency and the final process outcome quality. According to Schuh 2014, a critical point in Stages-gate processes is to keep up with the time plan since the work during the stages takes part in different departments and may not proceed at the same pace.

Therefore, Schuh proposed the method of synchronization and pulsing (ger: “Methode der Synchronisation und Taktung”) to combine a Stage-gate process with ideas from lean development (Schuh 2014). To hold up with the given time plan in between gates, different synchronization points with a fixed time gap (pulse) in between them are introduced. At these points work packages that were executed in parallel are compared, the overall progress is being determined, and if necessary further actions are needed, they are taken immediately rather than just at the gates. Thereby, it is more likely to finish the project within the planned time frame. This method was implemented and tested on the development process of the systems engineering department of a heavy machinery industry partner.

Paper submitted to:

R&D Management Conference 2016 "From Science to Society: Innovation and Value Creation" 3-6 July 2016, Cambridge, UK

Besides the standardized process, models a set of procedures is needed to introduce and maintain a standardized process. Reitz 2008 proposes twelve steps to accompany the realization of a standardized process. For our considerations, we clustered Reitz's steps into three main phases for a better understanding (planning, implementation, and controlling). Furthermore, we included an iteration loop at the end that repeats the last four steps for continuous reflection, improvement, and standardization of the development process (see Figure 1). For a first-time standardization, the steps 1 to 8 have to be conducted. Then, constant control and improvement must be performed (steps 9 to 12) in order to keep the standardized process (Reitz 2008).

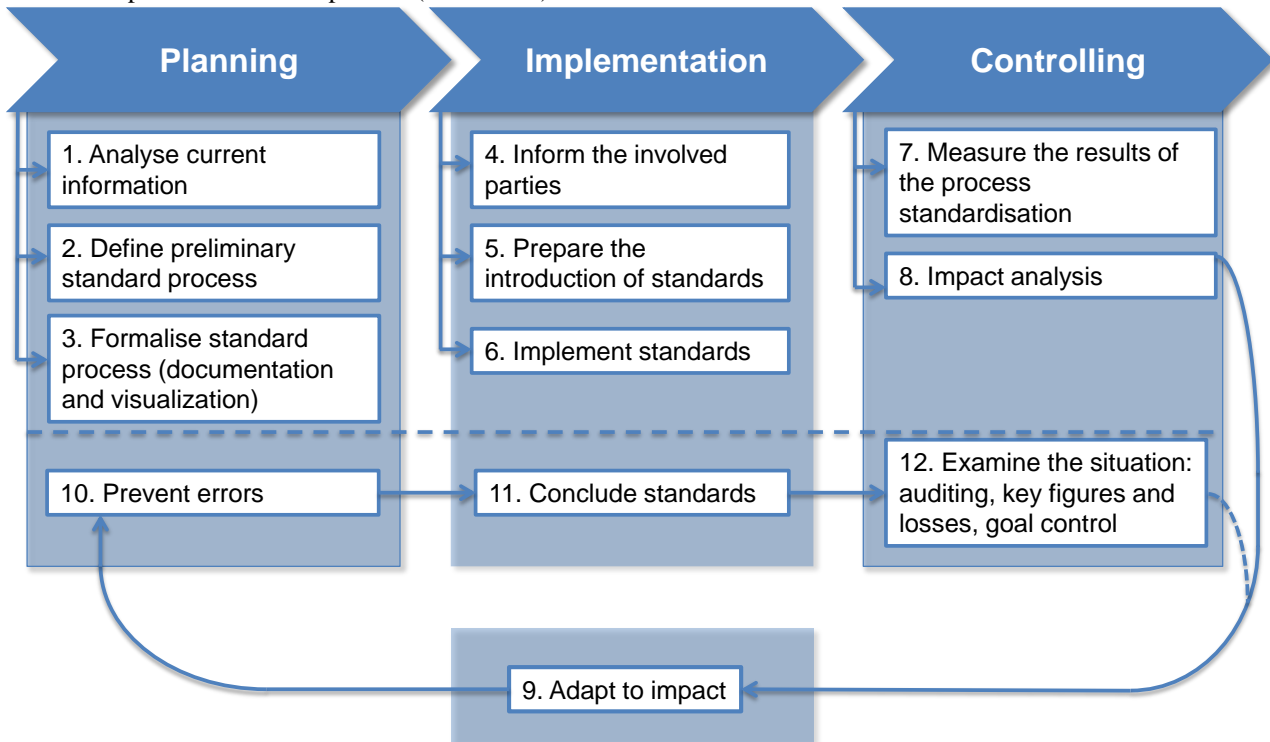


Figure 1. Steps to establish a process standardization (adapted from Reitz 2008)

2.2 Stage-gate Method

The Stage-gate method first described by Cooper (Cooper 1990) was initially designed for the development of innovative product solutions. It specifically deals with inherent project risk by defining gates, in which the quality of the stage's results is checked. Additionally, Cooper 2001 gives a detailed description of what is necessary to plan, implement, and maintain a proper Stage-gate process. In Cooper 2007 the Stage-gate concept is already adapted to manage technology development processes with the exemplary Stage-gate sequence depicted in Figure 2.

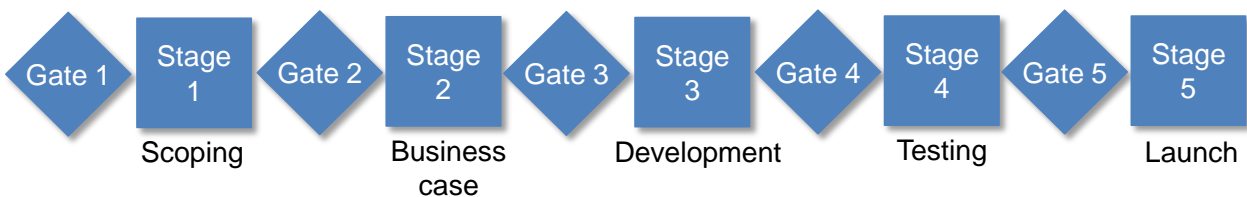


Figure 2. The standard Stage-gate New Product Process from Cooper 2007

During stages, processes are executed in parallel and decentralized, meaning in the different departments and possibly also for different solutions. Once a gate is reached, all solutions from the current stage that will be used in the upcoming stage have to pass through a quality assessment at the gate. A solution may consist of various deliverables (e.g. simulation results, expected costs, evaluated customer surveys) that are used to measure the solutions' agreement with the requirements (criteria). It is important to notice that only deliverables that passed through a gate and thus a quality assessment may be used in the upcoming stage. This shall prevent the process from going back to a previous stage once a gate is passed and accounts for a high quality basis for the beginning of each stage (Cooper 1990).

With regards to the requirements assessed at the gates, the method differentiates between should- and must-criteria. Must-criteria have to be fulfilled in order to continue to the next stage through the gate. These criteria may be answered with a simple yes or no (fulfilled or not fulfilled) (Cooper 1990). Should-criteria on the other hand are assessed based on a metric that resemble how good either one of the solutions fulfil a respective should-criteria. This makes it possible

Paper submitted to:

R&D Management Conference 2016 “From Science to Society: Innovation and Value Creation” 3-6 July 2016, Cambridge, UK to compare different solutions on a score-board with respect to their fulfilment of each of the requirements (Cooper 2007). Based on the results from the assessment a decision is made. Typical decisions are to continue the process (go-), repeat the current stage (recycle-), temporarily put the project to rest (hold-) or stop the project overall (kill-decision) for each solution. These decisions are typically made by an interdisciplinary team of decision-makers (gatekeepers) and are performed in a fixed manner (gate-routine) (Cooper 1990).

Explicit aims of the Stage-gate method are a better definition of the goals for each process step since the fulfilment of goals needs to be measured when passing through a gate on to the next stage. Furthermore, improved prioritization of activities and assurance of product quality can be enhanced due to the systematic assessment of all solutions. Thereby decision steps that lead to one solution or another are further made more transparent and ideally the solution that best matches the given requirements is chosen to be realized (Cooper 2007).

2.3 Business Process Model and Notation (BPMN)

For modelling and visualizing processes, there is a variety of methods in literature and practice. Just to name a few, possible methods are Event-Driven Process Chains (EDPC) (Keller 1992), SIPOC (Supplier Inputs Process Outputs Customers) (Rasmusson 2006), Value Stream Maps (VSM) (McManus 2005), and the Business Process Model and Notation (BPMN) (Dijkman et al, 2008).

The EDPC standard considers a flow chart that distinguishes between actions and functions that always come in alternating order. Additionally, organizational elements, data resources, and execution time can be included (Keller 1992).

SIPOC (Suppliers Inputs Process Outputs Customers) on the other hand results in a table that represents all process steps including inputs and outputs as well as the dependencies among them. It is most commonly used in six-sigma processes.

Value-stream maps as a lean specific modelling and visualisation tool offer the possibility to model processes as a series of activities with a constantly altered information flow connecting them (McManus 2005). By including cycle times and times in between them it enables a thorough analysis of the time dependencies among them and waste within the process.

Lastly, BPMN, the modelling language we considered in our approach, gives the flexibility to distinguish between activities and events, similar to EDPCs, but does not require an alternating order of these two. Some of the general symbolic notation of BPMN is depicted in Figure 3. BPMN considers objects that may be events, activities or gateways, as well as sequence and message flows. Sequence flows produce links and relations between different objects. Message flows on the other hand consider links and relations between different processes, thus on a different level of abstraction. A possibly useful feature about BPMN is that processes are easy to transform into a Petri net representation as outlined in Dijkman et al. 2008. Petri nets in turn open the possibility to analyse the dependencies within the process in a formal and automatable way (Van der Aalst 1998).

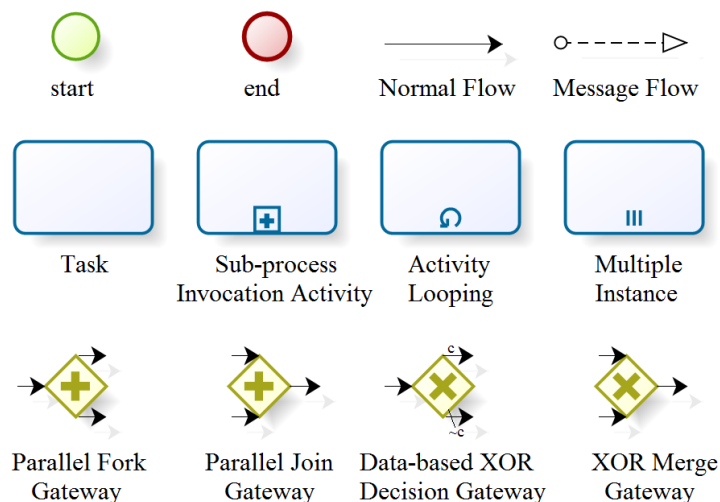


Figure 3. Basic notation of BPMN (Dijkman et al, 2008) (modelled using Bizagi Modeler (Bizagi BPM))

3. Approach for process standardization

As part of collaboration with a German industry partner from heavy machinery a concept to improve the development process was elaborated. In order to analyse the current situation, we performed an employee survey that resulted in the suggestion of a higher degree of process standardization to increase process efficiency, reproducibility, and product quality. The standardization approach should also be able to handle current aspects of the development processes like changing requirements and changing boundary conditions, as well as missing process inputs and changes in prioritization of activities.

In the following section, we explain the idea behind our proposed approach, which first introduces two methods to properly document and display the dependencies among process steps, as well as the verification criteria and methods currently used. Building up on this documentation, verification procedures are systematically revised and together with the dependency analysis used to design a Stage-gate process of different process levels. Subsequently, we provide insights into the actual application of our approach to a development process from the industry partner in a case study.

3.1 Approach

We took the idea of the Stage-gate method of assigning quality checks according to predefined criteria at certain points of the design process and adapted it in order to apply it at the level of more specific process steps (see Figure 4). Our approach aims at analysing the verifications realised continuously during the design process and at defining new verification methods, verification criteria, and roles based on the analysis. The approach presented in this paper covers the first step (analyse current information) and the second step (define preliminary standard process) of the steps to establish a process standardization depicted in Figure 1.

To perform our approach, we propose to use two main tools: an enhanced BPMN representation of the process and a process-table shown exemplarily in Table 1.

We used the Business Process Model and Notation (BPMN) since we saw the best possibility to integrate our information in the given notation and still result in an intuitive diagram. Regarding the other previously mentioned methods, we found they were not as well suited for various reasons. Value stream maps are too specific with regards to information flow and cycle times. SIPOC on the other hand allowed a thorough analysis of the interdependencies between the processes but does not include a specific notation that would result in an intuitive diagram. Lastly, we find that EDPC bear the risk of being too inflexible by always considering alternating events and functions (see section 2.3 for more information on BPMN and other process modelling techniques). In the following we assume that a proper BPMN model of the process to be analysed already exists.

The previously mentioned table (Table 1) is designed in such a way that the left side (yellow) is meant to document the current process (step 1), whereas the right side (blue) will be used to design a new preliminary standard process (step 2 of the standardization process). The enhanced BPMN representation is used to make the transfer between step 1 and step 2 easier and more descriptive. The goal is to implement verifications at all three layers: at the end of process phases, at each gate, and after every process step (Figure 4).

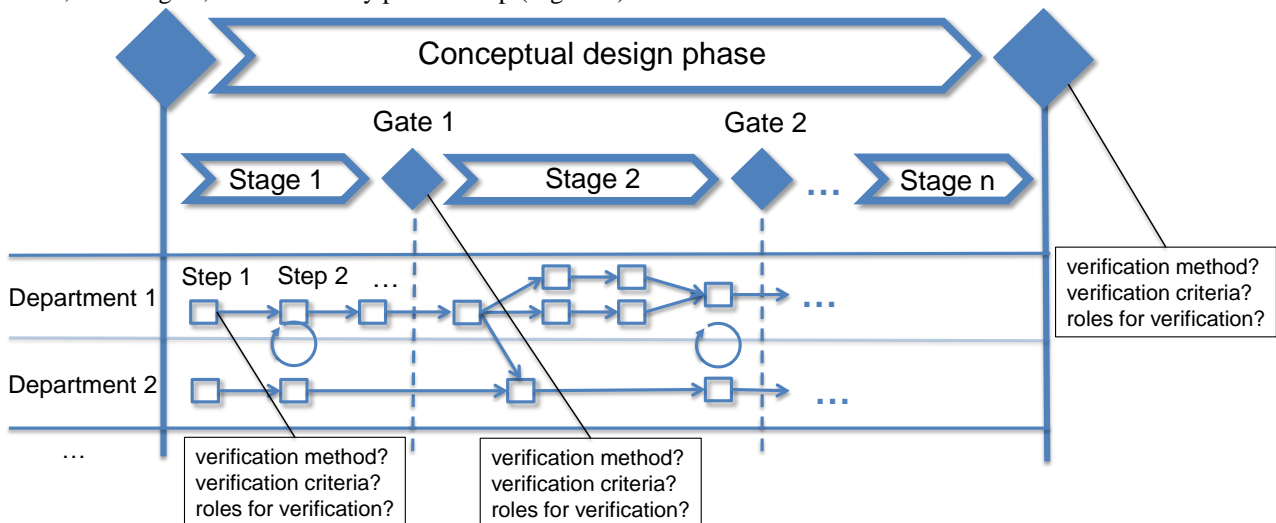


Figure 4. Consideration of verifications at the level of process phases, stages, and steps

Before beginning with the analysis, the phase of the design process that shall be analysed must be selected and the actors involved in the process phase must be identified. For a first-time realization, a process that is not too complex and well understood should be chosen to get familiar with the procedures. Then, the current process information must be gathered and visualized, e.g. via workshops with all stakeholders.

Paper submitted to:

R&D Management Conference 2016 "From Science to Society: Innovation and Value Creation" 3-6 July 2016, Cambridge, UK

Subsequently, this representation is used to contribute to the filling of the left side of Table 1 (analyse current information), in which several aspects of the current situation must be defined. The table includes the current process steps, their output, the criticality of the output for upcoming process steps, the verification method currently applied to verify this output, and the current criteria for verification.

We define criticality as the percentage of finalization that an output from one specific process step must have in order to enable the finalization of other specific process steps. Hereby we mean that when the output of one process is 100% critical for another one, the dependent process step can only be finished when the output of the previous step has also been completely finished and verified. A criticality of 50% thus means that roughly half of the previous steps' outputs must be finalized and verified to enable the dependent process's execution. Based on the current process steps from the BPMN as well as further detailed information about the current verification procedure during each process step, representatives from all involved departments are then called to discuss about the different steps' criticalities as well as unclear aspects of the verification procedure.

To analyse the verification process more deeply, we considered verification methods and verification criteria separately in the table. By verification method we mean how the results that are to be verified are produced e.g. through analytical calculations that result in clear values. By verification criteria, on the other hand, we mean how a decision is made based on these results e.g. through empirical values that made it possible to classify the previously calculated values as acceptable or unacceptable with regards to the requirements.

Table 1: Table for the analysis of current information and definition of new standards

Analyse current information						Define preliminary standard process			
Process Step	Output	Critical for	% of criticality	Verification method	Verification criteria	Gate	New verification criteria (must or should)	New verification criteria	New verification method
Step 1	Output 1	Step 5	100%	Two man rule	Employee experience	1	Company experience (should)	Internal benchmarking	Product manager
Step 2	Output 2	Step 1	50%	FEM simulation	Tables	1	Tables (must)	FEM simulation	Design engineer
		Step 5	100%						
...

Building up on the contents of the filled left side of the table, the previously used BPMN process model is enhanced by a representation of the criticality and its dependencies among the respective process steps (see Figure 5). For our specific notation, we used dashed lines to represent input or output of a task from its top or bottom side (not to be confused with the message flow in Figure 3). Additionally, we used magnified arrowheads that show the direction of critical dependency among tasks, symbolizing whether their inputs are critical influences or their outputs influence other process steps critically. The arrow tips are in turn filled depending on their percentage of criticality documented in the table. In enhancing the diagram it was found to be especially helpful to use a light colour (e.g. light grey) for the original BPMN process steps and a stronger colour together with a dashed line for the criticalities. This makes it possible to emphasize the criticality and include the original process structure in one diagram without confusing one for another (see Figure 5).

Note that there is no dashed line symbolizing the criticality between subsequent process steps in the same lane as the subsequent step may only be started once the previous steps have been executed. As a result, the criticality of a process step towards the step after the next gateway is always 100% if it is followed by another process step. To emphasize this aspect, the criticality between these steps and the steps after the gateway is included in the notation, even though it is redundant.

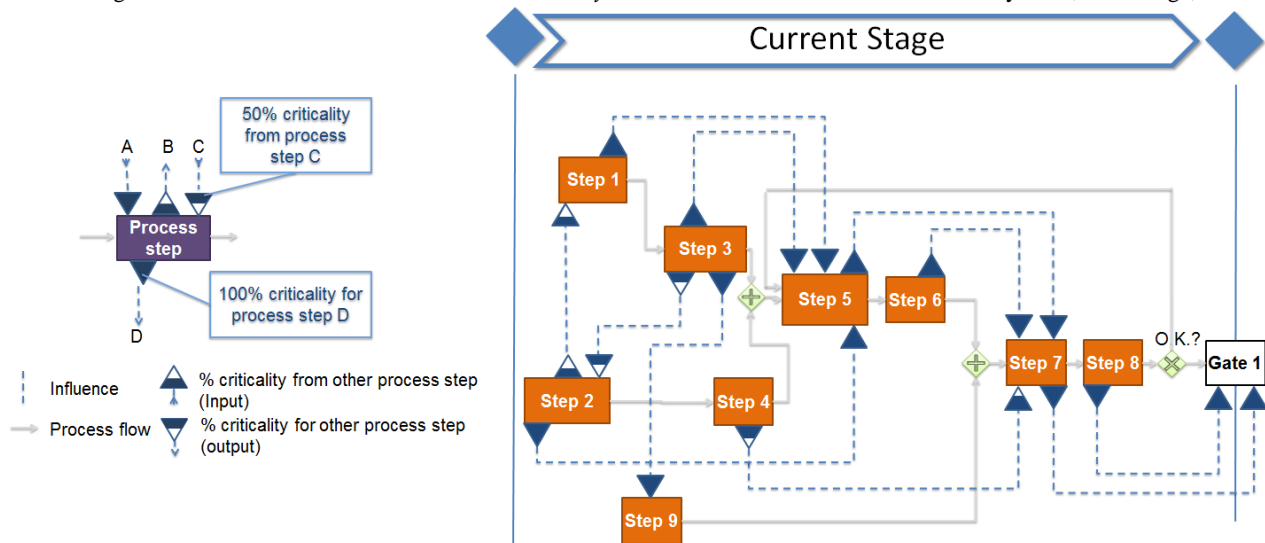


Figure 5. Proposed representation of current process steps

Once the left side of the table as well as the enhanced BPMN diagram is filled, all necessary process information is documented and it can be preceded with defining the preliminary standard process. To define a preliminary standard, first stages and gates must be defined and the enhanced BPMN representation contributes to that. In the following, we give examples on how the approach proceeds in placing gates. Nonetheless, it must be highlighted that every company has to define gates according to its own criteria.

The process steps that are influenced by a lot of other processes and therefore have multiple high input criticalities should be considered as possible points for gates. For example, the input criticalities of step 5 in Figure 5 add up to 300%. These elements are usually process steps where a lot of results are merged together. The same is true for process steps that influence a lot of other processes with a high criticality. An example would be step 3 in Figure 5 that has a cumulative outgoing criticality of 250%. However, it is an early step of the current stage and is part of a lane that runs parallel to another one so that it might not be useful to put a gate here. Appropriate steps are usually the ones where the workflow splits up and is performed in parallel in different departments or where a lot of parallel branches are merged (see step 5 in Figure 5). Often, these steps should also be followed by a gate since a lot of other processes highly depend on the quality of their results. On the other hand, process steps that have only few inputs with low criticality are not highly influenced by the outcomes of other process steps. Consequently, they are easily identified as process steps that can be executed in parallel.

Once the definition of stages and gates has been performed, each previously documented process step can be assigned to a specific gate, which is documented in the first column of the right side of Table 1 (define preliminary standard process).

Subsequently for each process step, the following information is filled in: new verification criteria, new verification method to verify the criteria, and roles in charge of verification. Thus, new criteria like financial considerations can be included for verification and new verification methods like simulations conducted by design engineers or simulation experts can be assigned. Where there is no need for new criteria or verification methods as there are existing elements, the content can be transferred directly from the left side of the table to the right. However, this transfer still triggers a discussion about current verification, thus ideally leading to improvements and increased awareness. In the case study, we relied on discussions based on experience that help to identify possible criteria to be revised.

To recall, must-criteria are those criteria that have to be verified at the end of the step, whereas should-criteria can be verified at the end of the step but the verification is not mandatory until the next gate.

At this point of the approach, the connection of the goals of process standardization (process efficiency, process reproducibility, and permanent product quality assurance) and the analysis of the should-criteria still needs to be performed. Therefore, once the entire table is filled, a closer look is taken at the should-criteria for each process step. Since previously process dependencies were analysed and captured in an enhanced BPMN diagram, the additional information can be taken into consideration. Thereby we mean that by including the dependencies, proper methods for the quality checks for each process step can be identified. Steps with a high output criticality may need more thorough and robust quality check methods since their results have a high impact on the process and its execution time as a whole. This means that while normally should-criteria during a stage transform into must-criteria at a gate, there might also be some process steps that are so critical that their verification is mandatory, leading to must-criteria already before a gate. Therefore, for each should-criteria considerations should be made. This ensures that still all necessary criteria are fulfilled but not earlier than they should, making the process highly flexible while still applying quality assurance at the right time. As a consequence, the resulting process is adapted to result in the most efficient alternative.

Finally, reproducibility is accounted for by revisions and documentation of the process and its dependencies.

In order to assess the previously introduced approach, we applied it in a case study in cooperation with a German industry partner of heavy machinery. Our work included the application of our proposed documentation and visualization approaches as well as some of the preliminary standard definition of the concept phase of two essential parts of the final product. In both cases, only the conceptual phase was analysed with special regards to simulations within the process. This is due to the fact that the small lot sizes in heavy machinery lead to a high demand for virtual prototypes as physical prototypes are very costly. Our first main goal was to see how the application to a real world process is performed and how the new approach is perceived by the industry partner. The development phases of both considered products had already been documented according to basic BPMN previous to our cooperation with the industry partner (see Figure 6).

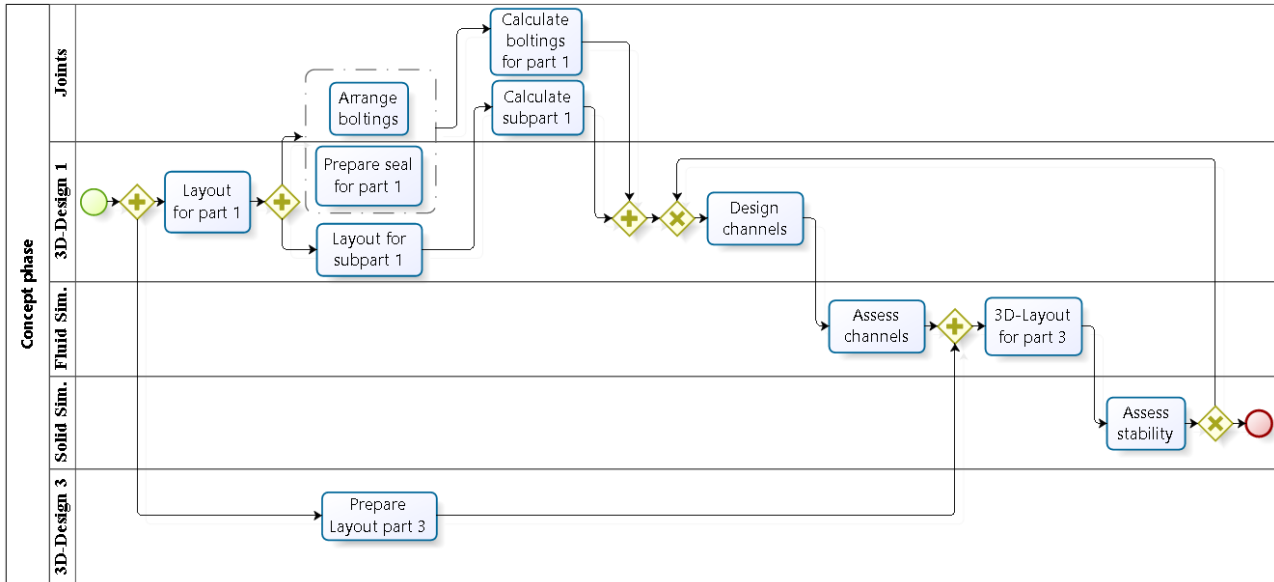


Figure 6: Schematic BPMN representation of the industry partner's previous concept phase (modelled using Bizagi Modeler (Bizagi BPM))

Furthermore, the process already included a few gate-like process steps. If this had not been the case, a previous step would have been necessary to create a proper process documentation in a BPMN diagram. Additionally, we held several workshops to gather additional information and fill the left side of the table through expert discussion (see Table 2). The input of the employees was especially helpful since a lot of the information, e.g. current quality methods, was not documented but rather based on common practice and experience.

Table 2: Filled table of the concept phase of the industry partner's development process after the workshops

Process Step	Output	Critical for	% of criticality	Verification method	Verification criteria
Prepare Layout of part 1	CAD-geometry	Arrange boltings & Prepare seal for part 1	100%	Discussion	Empirical values, thermodynamical boundary conditions
		Layout subpart 1	100%		
Arrange boltings & Prepare seal for part 1	Enhanced CAD-geometry	Design channels	100%	Analytical calculations	Empirical values
Calculate boltings for part 1	Screw dimensions, safety measures	Design channels	100%	Two man rule	Empirical values
		Design channels	50%		

Table 2 (cont.): Filled table of the concept phase of the industry partner's development process after the workshops

Process Step	Output	Critical for	% of criticality	Verification method	Verification criteria
Layout subpart 1	Enhanced CAD-geometry	Arrange boltings & Prepare seal for part 1	50%	Calculate subpart 1	Thermodynamical boundary conditions
		Arrange boltings & Prepare seal for part 1	100%		
Calculate subpart 1	Geometrical data	3D-Layout part 3	80%	Interview with suppliers	Feasibility
Design channels	Enhanced CAD-geometry	3D-Layout part 3	100%	Optical revision	Realization of thermodynamical requirements
Assess channels	Release or revision advises	3D-Layout part 3	100%	Two man rule	Values from experience
3D-Layout part 3	Enhanced CAD-geometry	Layout Release	100%	Matching with the requirements; benchmarking with previous products	Requirements from interfaces; geometrical benchmarking
Assess stability	Release or revision advises	Layout Release	100%	Two man rule	Empirical values

Furthermore, it was found helpful to work with colours highlighting the department involved in the process steps' execution that were all included in an additional legend. Within the workshop group we stimulated a discussion about the criticality and the currently employed verification methods. Once we found the group to have a good feeling for the filling of the table it was left up to the participants to finish up the rest of the table. In Table 2 we differentiated between construction steps (grey rows) and verification steps (orange rows).

With the completed table all current information of the process was available to produce an enhanced BPMN representation of the process (see Figure 7). The numbering of the process steps was added so that it was easier to make the connection between the two representations in the table and the BPMN chart.

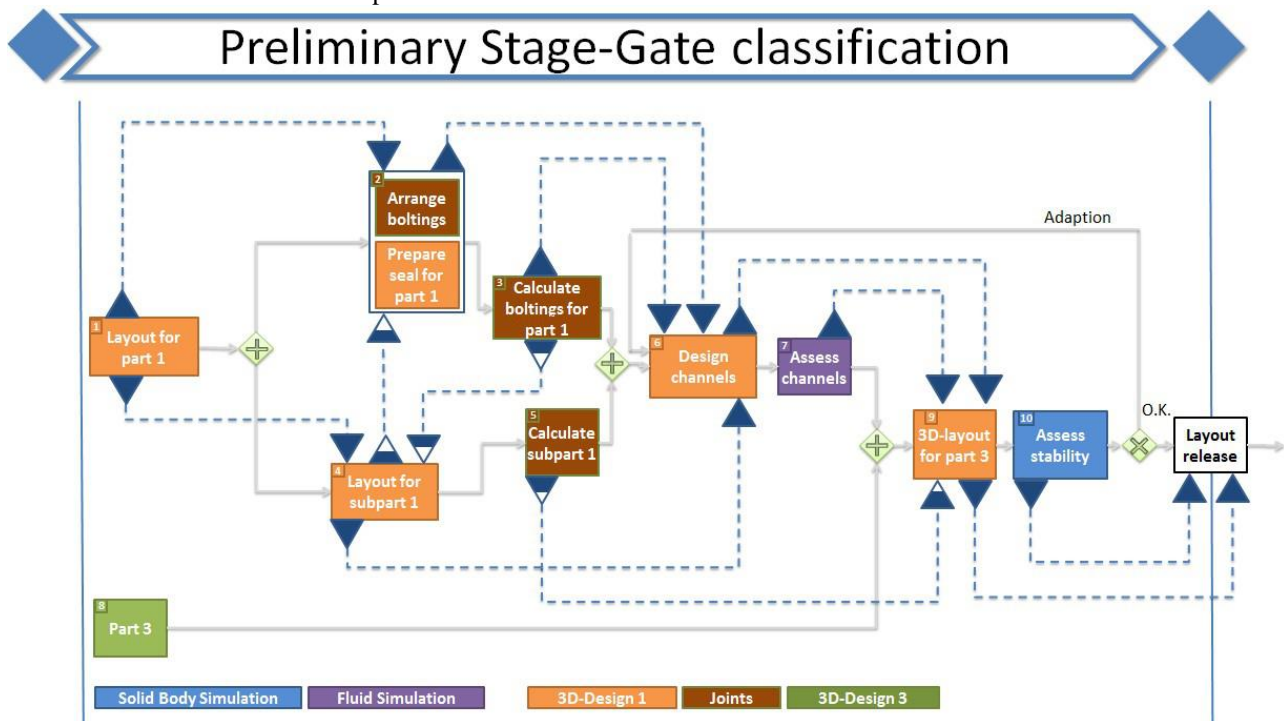


Figure 7: Enhanced BPMN representation of the industry partner's concept phase including criticality

Paper submitted to:

R&D Management Conference 2016 *“From Science to Society: Innovation and Value Creation”* 3-6 July 2016, Cambridge, UK

Based on this graphical representation of the process, first suggestions of the critical process steps were identified and recommendations on how to place the gates were developed. These proposals were then discussed with an executive member of the industry partner, who gave input on how he thought the given information should be used and what further actions should be taken based upon our recommendation. These discussions, in some cases with other stakeholders of the company and with some review loops, results in the process depicted in Figure 7. In contrast to the version already available at the start of the project, the new process includes the relations between different process steps and the corresponding criticalities.

As opposed to our initial concept the industry partner decided to implement a simpler version of the approach with the aim of lower implementation effort. Rather than considering should- and must-criteria separately and making further differentiations between them at the gates, the industry partner decided only to use must-criteria to guarantee that each criteria was necessarily executed. Naturally, this took away the possibility to compare different solutions and the flexibility to delay some of the criterias' fulfillment until the next gate is reached. Nonetheless, multiple solutions are usually not considered anyway in most of the industry partner's projects, so that there is less need for comparing different solutions anyway. Additionally, it made the implementation easier, since less distinctions had to be made. Once the Stage-gate structure was created, we encouraged the industry partner to reflect its current criteria and work on elaborating new verification criteria. The interrelations between process steps and their criticalities were considered very helpful at this point by the industry partner. Up to today, only the first version of a preliminary standard as in Figure 7 have been defined but has not yet been reflected and improved in an additional workshop with us. In addition to the previously described project phase, we have started considering a second and more complex phase in the industry partner's development process that also includes dependencies with other project phases. Here we are still in the analysis phase but plan to proceed with further measures in the next months.

Our case study showed us that our proposed method is indeed applicable to a real world process in an industrial setup. Feedback from the industry partner supported our intention to make dependencies among process steps clearer and facilitate the systematic standardization of a development process phase. An issue currently part of our investigation is how to systemizes the whole process. This especially deals with the still open point on how to systematically choose the proper verification method.

4. Conclusions and Further Work

In this paper, we proposed a new approach for documenting, analysing, and standardizing a given initial process with respect to an enhanced design verification. The goal is to represent a given process phase as a Stage-gate process in order to have quality checks (gates) where really needed and making it possible to parallelize working packages during the stages. During analysis, the process is therefore documented in a process table whose outputs are used to represent the current process flow in an enhanced manner. Subsequently, the process flow is used to identify gates in an easy and demonstrative manner. Once the gates have been identified, verification criteria can be revised and finally a preliminary standard process can be defined. We believe that by using our approach a proper documentation can be achieved and through an intuitive and demonstrative representation of the process a revision and preliminary standardization of the process can be achieved systematically.

The main advantage of our approach is the combined analysis of verifications at two levels: after each design step and at the end of each design phase. The combination allows a detailed definition of continuous verifications within the process. Meanwhile, it still maintains the necessary flexibility, as some criteria are left open for verification at the end of design steps to verify them at the gates.

The approach was implemented in a case study within the design process of a German industry partner of heavy machinery. The participants consider the process representation of great benefit for the definition of new standards. For further work, we will focus on systematizing the selection of new verification methods for the preliminary standard process. Especially the early use of simulations like finite element analyses is a promising option for profound verification. Questions like which methods can be considered or which criteria must be applied for the selection of a method will be investigated. Furthermore, a point still left open is how to deal with dependencies among different phases of different processes. As mentioned previously, this point is currently investigated in a second case study in the industry partner's development process.

Additionally, we plan to elaborate a more systematic approach to lead to the new verification criteria (right side of the table), since this is still based on discussion with specific applicable rules that would make use of criticalities or gate structures. Furthermore, we believe that our notation can still be enhanced since we only used the most rudimentary elements of the BPMN notation and left out entire concepts like exceptions, messages, and loops. Through the extension we then hope to be able to provide a tool to analyse and redesign even more complex processes with cross-links in a standardized way. A future prospective may also be to analyse a possible mapping to Petri Nets, which could in turn help to perform a formal dependency analysis automatically and would allow integrating the methodology into a software.

References

- Ballard, G. 2000. "Positive vs negative iteration in design". Proceedings Eighth Annual Conference of the International Group for Lean Construction, IGLC-6, 17-19, Brighton, UK.
- Cooper, R.D. 1990. "Stage-gate Systems: A New Tool for Managing New Products". Business horizons 33(3): 44-54.
- Cooper, R. D. 2001. "Winning at New Products". 3rd ed. Perseus Publishing.
- Cooper, R. D. 2007. "Managing Technology Development Projects". IEEE Engineering Management Review 35 (1): 67-76.
- D'Albert, H., Carro Saavedra, C., and Lindemann, U. 2015. "Elicitation of Requirements for a knowledge-based Framework in Product Development Process". International Conference on Knowledge Management (ICKM). Osaka, Japan.
- Dijkman, R. M., Dumas, M., and Ouyang, C. 2008. "Semantics and analysis of business process models in BPMN". Information and Software Technology 50(12): 1281-1294.
- Erlach, K. 2010. "Wertstromdesign – Der Weg zur schlanken Fabrik". 2nd ed. Berlin Heidelberg: Springer: 12.
- Ehrlenspiel, K. 2003. "Integrierte Produktentwicklung". 2nd ed. Hanser: 202-207.
- Keller, G., Nüttgens, M. and Scheer, A.-W. 1992. "Semantische Prozeßmodellierung auf der Grundlage Ereignisgesteuerter Prozeßketten (EPK)". Institut für Wirtschaftsinformatik (IWi), Universität des Saarlandes.
- Lake, J. V. 1999. "V & V in Plain English". INCOSE International Symposium 9(1): 1134-1140. Brighton, England.
- Maier, A., Dönmez, D., Hepperle, C., Kreimeyer, M., Lindemann, U., and Clarkson, J. 2011 "Improving communication in design: recommendations from the literature". Proceedings of International Conference on Engineering Design, ICED11.
- McManus, H. L. 2005. "Product Development Value Stream Mapping". Cambridge, MA: Massachusetts Institute of Technology-Center for Technology, Policy, and Industrial Development.
- Oehmen, J., Rebentisch, E. 2010. "Waste in lean product development. Lean Advancement Initiative".
- Oppenheim, B. W. 2004. "Lean Product Development Flow". Systems Engineering 7 (4).
- Pahl, G., Beitz, W., Feldhusen, J., and Grote, K. H. 2007. "Engineering Design: A Systematic Approach". 3rd ed. Springer: London.
- Rasmusson, D. 2006. "SIPOC Picture Book: A Visual Guide to SIPOC/DMAIC Relationship". Oriel Incorporated.
- Reinertsen, D. G. (2009). "The principles of product development flow: second generation lean product development". Redondo Beach: Celeritas. Vol. 62.
- Reitz, A. 2008. "Lean TPM: In 12 Schritten zum schlanken Managementsystem". Mi-Wirtschaftsbuch: Munich.
- Schuh, G. 2014. "Der standardisierte Entwicklungsprozess".
http://www.konstruktionspraxis.vogel.de/themen/digitale_konstruktion/projektplanung/articles/470280/, accessed on 14.06.2015.
- Spath, D., Scharer, M., Landwehr, R., Forster, H., and Schneider, W. 2001. "METHODEN-Tore öffnen-Quality-Gate-Konzept für den Produktentstehungsprozess. Qualität und Zuverlässigkeit" 46 (12): 1544–1551.
- Van der Aalst, W. M. 1998. "The application of Petri nets to workflow management". Journal of circuits, systems, and computers, 8(01), 21-66.
- Verworn, B., Herstatt, C. 2000. "Modelle des Innovationsprozesses. Working Papers/Technologie-und Innovationsmanagement", Technical University Hamburg-Harburg.

Paper submitted to:

R&D Management Conference 2016 “*From Science to Society: Innovation and Value Creation*” 3-6 July 2016, Cambridge, UK

Verworn, B. 2000. “*Modelle des Innovationsprozesses*”, working paper, access from:

https://www.tuhh.de/tim/downloads/arbeitspapiere/Arbeitspapier_6.pdf .

Weber, F. 1999 (act. 2002). “*Concurrent Engineering – Die Reduzierung der „Time-to-market*” ”. Online (accessed on 29/01/2016): http://home.arcor.de/frithjof.weber/download/Weber_1999_Concurrent_Engineering.pdf