Approach for the Systematic Implementation of Quality Gates for the Planning and Control of Complex Production Chains

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For many companies the set-up of new production process chains is a highly complex task. Often these projects fail or deliver results which do not meet the expectations. Among the main reasons for failure are the lack of know-how of the project members and an insufficient detection and harmonization of technical and informational interfaces within the process chain. One of the most established approaches to address the described problem is the Quality Gate concept. This concept helps to manage a complete process by planning and controlling all activities within the process steps and has proven to be a capable tool for this task. Currently no systematic approach exists which provides a support for the implementation of the Quality Gate concept for a specific process. This paper proposes a method for the determination and arrangement of all the important information to successfully set up the Quality Gate approach for a new production process chain.

Keywords: quality gates; production process chains; quality management

1 Introduction

The research on new technologies and their first-time application in the production line is becoming a key element of competitiveness for the manufacturing industry in Europe. As low-wage countries expand their technological knowledge base in a steadily rising speed in the last years, it is crucial for European industrial companies to be a first mover regarding the usage of so far unestablished manufacturing technologies. As on the one hand the application of novel technologies can contribute to strengthen the companies' market position, on the other hand the set-up of a new production process chain is accompanied with certain challenges.

In the set-up and ramp-up phase, a production process chain which is based partially or completely on new manufacturing technologies can be considered as a complex system. A process chain usually consists of several process steps with extensive dependencies at the technological interfaces between the individual process elements. The real or perceived complexity of a process chain is related to the amount and variety of information which has to be processed. Due to the variety and a lack of information in the ramp-up phase of a process chain the complexity is quite high [ElMaraghy et al. 2005].

Therefore the process planning and manufacturing control are tasks of high importance in the course of implementing a new production process chain. In this context process planning can be described as all planning tasks arising to guarantee the production-oriented manufacturing of products while manufacturing control includes all tasks that are necessary for a processing in accordance with the process planning guidelines [Denkena et al. 2006]. To overcome the challenge of complexity in the set-up and ramp-up phase, approaches to assist the planning and control activities are needed.

Technical literature offers several approaches which aim to support these activities. As will be shown in the following, certain approaches proved to be suitable tools for this task, whereas the Quality Gate concept appears to be the most promising one. As shown in different studies in the past, the Quality Gate concept can be seen as powerful tool for the planning and control of process chains with new manufacturing technologies, once all the information and knowledge needed for the utilisation of the approach is collected and prepared properly. Still, there is a lack of methods which support the preparation of the Quality Gate concept. This paper describes a method for determination and arrangement all the important information to set up the Quality Gate approach for a new production process chain.

2 Existing Approaches for the Planning and Control of Complex Production Process Chains

In the past several approaches have been developed to address the challenge of planning and controlling a new production process chain. Some of the approaches concentrate on only one crucial aspect of the described problem while others are of a more holistic nature. One of the more specific approaches was introduced by Alisantoso et al. They emphasize, that in general the planning of a new production process chain is based significantly on information provided by the product design phase. In the design phase the designated function of the product is transferred into corresponding product features. In order to cover all types of information that needs to be considered in the design phase, the authors propose a design representation scheme for an effective product development. The representation scheme focuses on the communication among all stake holders in the design phase to ensure a mature design concept as a crucial basis for manufacturing planning [Alisantoso et al. 2006]. Another approach was presented by Denkena et al. Their work concentrates on the dependencies within a process chain by introducing a template-based methodology for building and evaluation of complex process chain models to design technological interfaces between the process steps [Denkena et al. 2006].

The probably most established holistic approach is the Quality Gate concept, which has been discussed in literature often. The concept is based on the stage-gate system by Cooper, initially presented in 1991 and refined in several publications later on [Cooper & Kleinschmidt 1991; Cooper 1994; Cooper 1996]. The stage-gate system mainly focuses on managing the product design process. Following this system the process is divided into several sequential phases with clearly defined activities. After each phase the results are evaluated in a management review and the decision is made whether the next phase of the process should be started or not. Later the stage-gate system has been evolved into an approach to plan and control not only the product design process but every type of business process, the so called Quality Gate concept.

The Quality Gate concept uses results-oriented breakpoints within a process chain, called Quality Gates, to plan and control all activities within a specific process. Therefore the progress of a process is evaluated according to certain criteria defined prior to the process start. One important criterion is the fulfilment of deliverables which has to be exchanged between different process steps. Compared to Milestones Quality Gates are flexible in time, but not regarding the expected results of a process phase. Thus Quality Gates can not be passed by and serve as a point of synchronisation of process results. With the support of checklists at a quality gate the decision is made whether the process results are sufficient to enter the next process phase or not. Quality Gates help to break down the overall requirements on the final process result into sub-targets for the single process steps and to clarify the internal dependencies of the process chain. Hence the quality of the single process step output is measurable and controllable for every process participant. Also the productivity and process capability can be controlled more easily. In summary the Quality Gate concept helps to overcome the complexity in the planning and control of production process chains [Scharer 2001; Valeri & Rozenfeld 2004; Prefi 2003; Hawlitzky 2002].

The applicability of the Quality Gate concept was proven in the past, especially in the software, aviation and automotive industry [Pryke et al. 1997; Pfeifer et al. 2004]. As could be shown in these sectors, the precise definition of the criteria at the Quality Gates is of great importance for the success of the approach as a whole. If the defined criteria do not represent the measurand critical for the results quality, the Quality Gate concept must fail completely. Today, there is no suitable approach available which supports the set-up of a Quality Gate concept for a new production process chain. In the following, such an approach is presented.

3 Approach for the Set Up of a Quality Gate Concept

The approach described in this paper was developed within the international Transregional Collaborative Research Centre SFB/TR4. The major objective of the project is the design and implementation of consistent process chains that enable the cost-effective mass production of complex optical components, such as lenses with aspherical or free-form surfaces. Basic elements of these process chains are, besides the process steps optical design, mould making, coating and measurement, the replication technologies precision glass moulding and injection moulding of polymers. Compared to the conventional

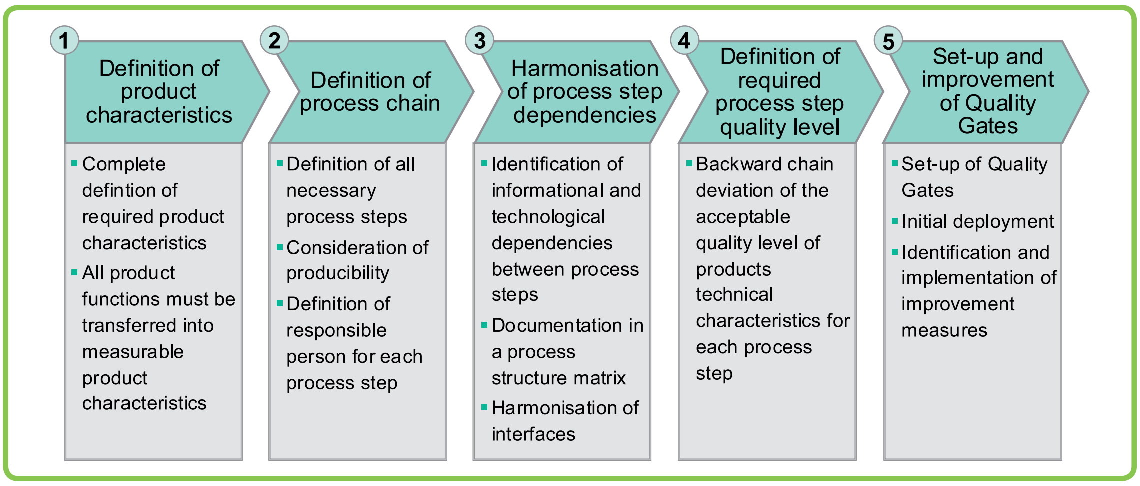

Figure 1: Approach for the Set Up of a Quality Gate Concept

technologies of direct processing for the manufacturing of complex optical components these replication processes provide an enormous technological and economic potential, though they are rather new technologies in this field of industrial application. Therefore considerable efforts are currently made to analyse and implement these new key manufacturing technologies not only in research projects like the SFB/TR4 but also in the optics industry in Europe [Brinksmeier et al. 2004].

A major challenge for the research activities within the project was to establish an approach for the planning and control of the production process chains in order to assure a high quality of the produced optical components. After an investigation of existing approaches the Quality Gate concept was stated the most suitable solution, as shown above, and thus was chosen for this task. The research then focused on a systematic and goal-oriented set-up and implementation of the Quality Gates concept. This finally resulted in an approach described in the following.

The approach consists of five sequential steps which cover the complete process of implementing a Quality Gate concept for a new production process chain (see figure 1). For an adequate result it is necessary to completely follow through all the process steps every time. Because each step depends on the output of the previous one, all five steps can be regarded as of same importance.

The first step aims to describe the desired final product in a detailed way. Here the differentiation of the desired product functions and the product characteristics necessary to realise these functions is of great importance. Usually the customer only is able to articulate the required product functions in detail. The requirements have to be collected and documented as complete and detailed as possible. Depending on the complexity of the product and the available information an intensive interaction with the customer is necessary. However, the following steps of the approach depend on the definition of the product characteristics. Thus, within the first step of the approach all product functions have to be transferred into product characteristics. After passing through the complete production process chain this product definition provides a basis for the evaluation of the final output. Suitable tools to support the derivation of customer requirements and the definition of product characteristics are the Conjoint Analysis or the Quality Function Deployment. A detailed description of their application will not be given at this point.

In the following step of the approach, all process steps necessary to manufacture the defined product have to be compiled. The individual steps have to be differentiated clearly from each other, as well as the arrangement of the steps to a process chain must be specified. A visualisation of the process chain in the form of a flow chart clarifies the planned process steps in an understandable way. An important aspect in the context of the process steps definition is the productivity of the aimed product. Technical restrictions of the single process steps have to be considered, for example the ability of a manufacturing technology to process a certain material or to handle a work piece of a specific geometry. Finally, for each process step a person has to be assigned which in the following is responsible for this part of the process chain.

In the next two steps of the approach, the dependencies within the process chain have to be identified, documented in a structured way and finally harmonised. In this context a dependency is generally characterised by a significant interaction between two different process steps influencing the process step or even the process chain result. Two types of dependencies can be differentiated: informational and technological dependencies. An informational dependency between two process steps is given, if one process step depends on a specific document, the result of a calculation or any kind of information of another process step. In comparison, a technological dependency always refers directly to the processed work piece. A technological dependency exists if the quality of processing a work piece strongly depends on

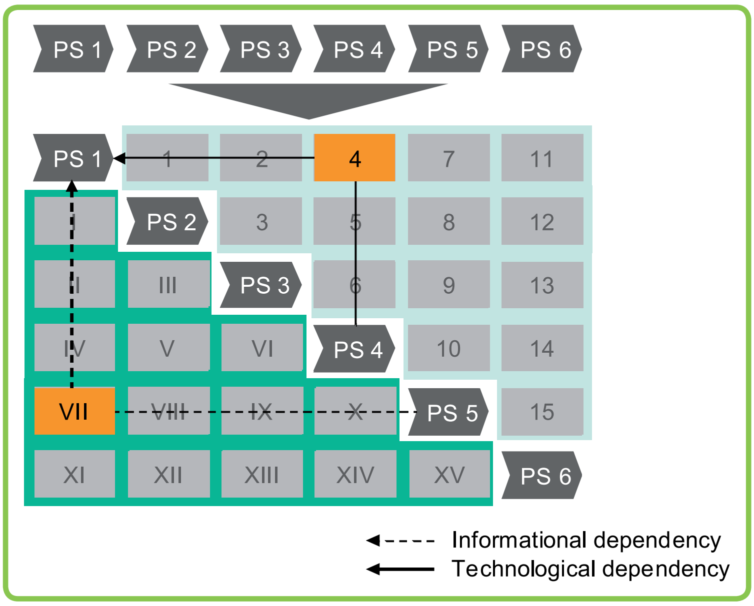

Figure 2: Process Structure Matrix for Documentation of Dependencies

the processing result of a previous step in the process chain. Especially technological dependencies which have an influence on the required final product characteristics have to be considered in this course. Usually, for the informational dependencies it has to be assumed that they do not only exist on the interfaces between sequential process steps, but also between all process steps, whether directly linked or not. Therefore it is clear that the documentation of the interfaces is quite complex and has to be regarded in the following steps of the approach.

In the third and fourth step the dependencies between the process step are considered closely. In the beginning of the third step all data to describe both the informational and technological dependencies is gathered. For that purpose the responsible persons of every single process step have to be involved e. g. by an interview or a workshop. In interaction with these persons two kinds of data have to be collected for every process step: on the one hand all input relevant to the work of single process step (documents, specifications, prepared work pieces etc.), on the other hand all results or output the process step creates (information, processed work piece etc.). For every input the process step coordinators must state a source they assume the input to come from, and equivalently for every output a recipient process step must be stated. Finally the data has to be classified as belonging to an informational or technological dependency. To cover all the in- and output data it is mandatory that the persons responsible for the process steps has sufficient experience in their technological field.

When the in- and output data of all process steps is completed the approach continues with step three using a so-called "process structure matrix" (PSM). On the main diagonal of the matrix the initial process steps will be arranged. Each of the remaining cells illustrates a dependency between two process steps. The cells on the left of the diagonal represent the informational interfaces, the technological ones are stated in the right half (see figure 2). The informational dependencies are then documented in the left half of the matrix. For every process step all the information, documents or specifications exchanged with previous and following process steps are documented for each interface accordingly the results of the interviews or workshops. Afterwards, the technological dependencies are accordingly described on the right side of the matrix.

Once the data is filled in the matrix, the informational interfaces between the process steps can be harmonised. For this purpose it has to be checked if every process step is aware of the output which is expected from it and if it is able to fulfil the demand. Also it has to be controlled if the output a process step assumes to have to provide is indeed needed by another process step. If it becomes clear that an interface is not well defined, the persons which are responsible for the involved process steps have to agree on the interface characteristics and document the result in the matrix.

In step four of the approach the focus is on the technological interfaces and their meaning for the process chain final result. In order to generate a product which meets the required specifications at the end of the process chain, the information about the technological interfaces must be used to work out the influence of every single process step on the final product characteristics. Usually it is easy to determine the impact of the last process step on the final product, because the interactions are quite obvious. Compared to this it is more difficult to identify the influence of the first steps in the process chain on the final result, although sometimes their contribution is crucial due to technological dependencies with following steps.

For that purpose the process chain should be considered process step by process step beginning with the last one and proceeding to the start of the chain. With support of the information about the technological interfaces given in the right side of the matrix every process step has to be evaluated regarding its technological impact on the final product characteristics or the following process steps. If an influence can be identified a corresponding Quality Gate criterion for this process step has to be defined. This criterion must on the one hand specify the characteristic of the work piece which has to be checked and the accompanying quality level, documented as a tolerance value or a limiting value, which has to be met. The quality level of the criteria always has to be chosen under consideration of the corresponding characteristic of the final product. On the one hand the quality level of the criteria must be defined in a way that finally the required characteristics of the final product are met. On the other hand a rising quality level causes higher process demands, so the quality level should be chosen as low as possible. For product characteristics which depend on the contribution of several process steps it is normally necessary to raise the quality level in direction of the process chain start with each process step to compensate the deviation every process step adds.

The last step of the approach starts with the set-up of the Quality Gates. Therefore the output of information agreed upon in step 3 and the technological criteria defined in step 4 are allocated to the single process steps and finally transferred into a Quality Gate list for each process step. Each Quality Gate list should be subdivided into informational and technological criteria. Further on for each criterion the customer of the information has to be listed. As defined in the Quality Gate approach the status of each criterion is marked by colours: green stands for a criterion which is met completely, a yellow colour means that with suitable measures the criterion still can be fulfilled in an acceptable time, red stands for a criterion which can not be reached anyway. In the following, after every pass through of the process chain the content of the Quality Gates lists must be examined and improvements have to be done if necessary.

4 Conclusion

An approach for the systematic and goal-oriented set-up and implementation of the Quality Gates concept for new production process chains has been proposed in this work. The aim of the approach is to assist the complex planning and control activities in the set-up and ramp-up phase of new production process chains. The approach consists of five sequential steps which cover the complete process of implementing a Quality Gate concept. In the first two steps the aimed product characteristics and the process steps necessary to manufacture the product are defined precisely. In step three the dependencies between the process steps are identified and documented in a so-called "process structure matrix". To have a clear overview of the existing interfaces informational and technological dependencies are differentiated in this step. Afterwards the informational dependencies are harmonised by consideration of each interface between the single process steps. The technological dependencies are used to examine the influence of the single process steps on the desired process chain result and to define corresponding Quality Gate criteria. For each Quality Gate criterion the characteristic of the work piece which has to be checked and the accompanying quality level has to be specified. In the last step of the approach the set-up of the Quality Gates follows. Both informational and technological dependencies are considered to define the content of each Quality Gate for the single process steps. Finally, the Quality Gate concept can be applied with the focus on a continuous improvement.

5 Acknowledgment

The support of the Deutsche Forschungsgemeinschaft (DFG) through the SFB/TR4 is gratefully acknowledged.

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