Virtual Quality Management: 6-Sigma based layout of Quality Orientated Process Models

Albert Weckenmann
Friedrich-Alexander-University Erlangen-Nuremberg
Chair Quality Management and Manufacturing Metrology
Albert.Weckenmann@qfm.uni-erlangen.de

Martin Bookjans
Friedrich-Alexander-University Erlangen-Nuremberg
Chair Quality Management and Manufacturing Metrology
Martin.Bookjans@qfm.uni-erlangen.de

Keywords: Virtual Quality Management, Six Sigma, Process Design, Simulative Dimensioning of Quality Techniques

Categorization: Research Paper

1 Introduction

Extensive and efficient quality management throughout all phases of the life cycle of a product is a crucial requirement for a successful business. This is of particular importance for products which are manufactured by innovative processes and for rapid market launches because of the stress of competition.

To manage this challenge, simulation methods are used to optimize the design of processes, process chains and systems with respect to economic efficiency and process-time (Weigert, 2002). In many cases impacting influences and dispersions of machine parameters during the process run are identified and represented inadequately, so reliable predictions about the quality capability of the process cannot be made. The difference between the simulated and the real process is shown in figure 1.

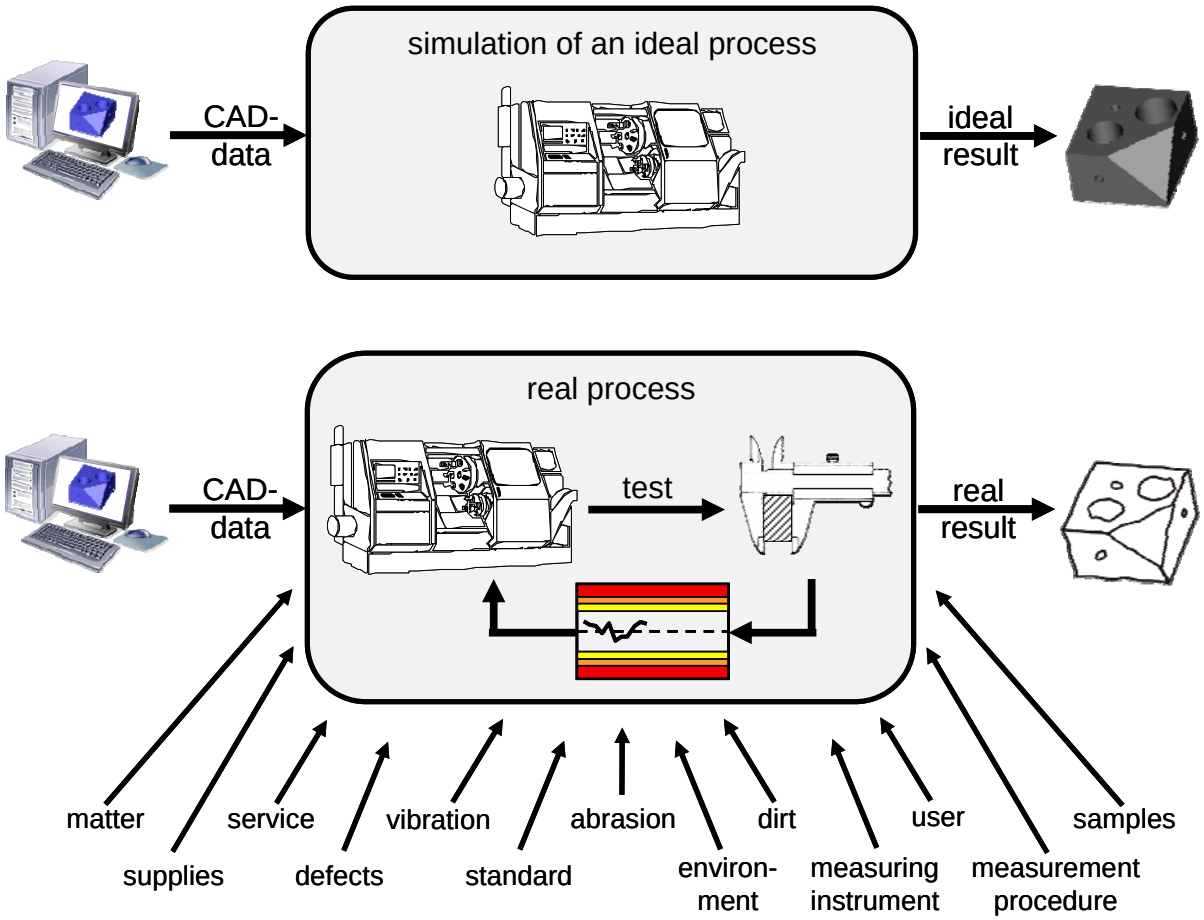

Figure 1: Difference between a simulation model and reality

Dispersions of the real process are typically remedied by the "imposition" of QM-measures after starting the serial production when the real process ramps up. That leads to a significant loss of time and causes a lot of additional effort. To avoid this inefficient practice, simulation models have to be enlarged significantly by enclosing environmental influences and scattering of process parameters. The approach to use the enormous potential of these models and process simulation software to increase the informational value of simulation studies, is called Virtual Quality Management (vQM). By use of vQM, simulation results can be the base for the design of the process with regard to layout, maximal output and robustness and

moreover for the virtual design and optimization of quality management measures. So it is aspired, that a process with a technically matured QM-tool is available when the series production starts and optimal quality can be achieved "right from the beginning".

This paper contains a general overview of the Virtual Quality Management methodology and a detailed consideration of the guidelines for the efficient proceeding in building up these specific process models.

2 What is Virtual Quality Management?

Virtual Quality Management can be defined as "coordinated approaches to the efficient modeling, adaptation, utilization and analysis of simulation studies for generating resilient knowledge and dimensioning quality techniques for products and processes during the planning stage."

Figure 2 shows the content of this approach and its most important facts. Miscellaneous information about the ideal manufacturing process and the product are used as base for the model-building (process knowledge). This is the same proceeding like working with "ideal"-models. But these Quality Orientated Process Models have to be supplemented with a lot of information about the imperfection of the process and the impact of environmental influences. This has the positive effect that the accuracy of the model increases so much, that in addition to forecasts about the value of ideal process parameters, statements according to quality capability and robustness can be made. But this extra information has to be gained by the increasing complexity of the process model. In order to keep the additional work low, guidelines have been prepared and validated, which help to design such Quality Orientated Process Models efficiently and to handle the complexity.

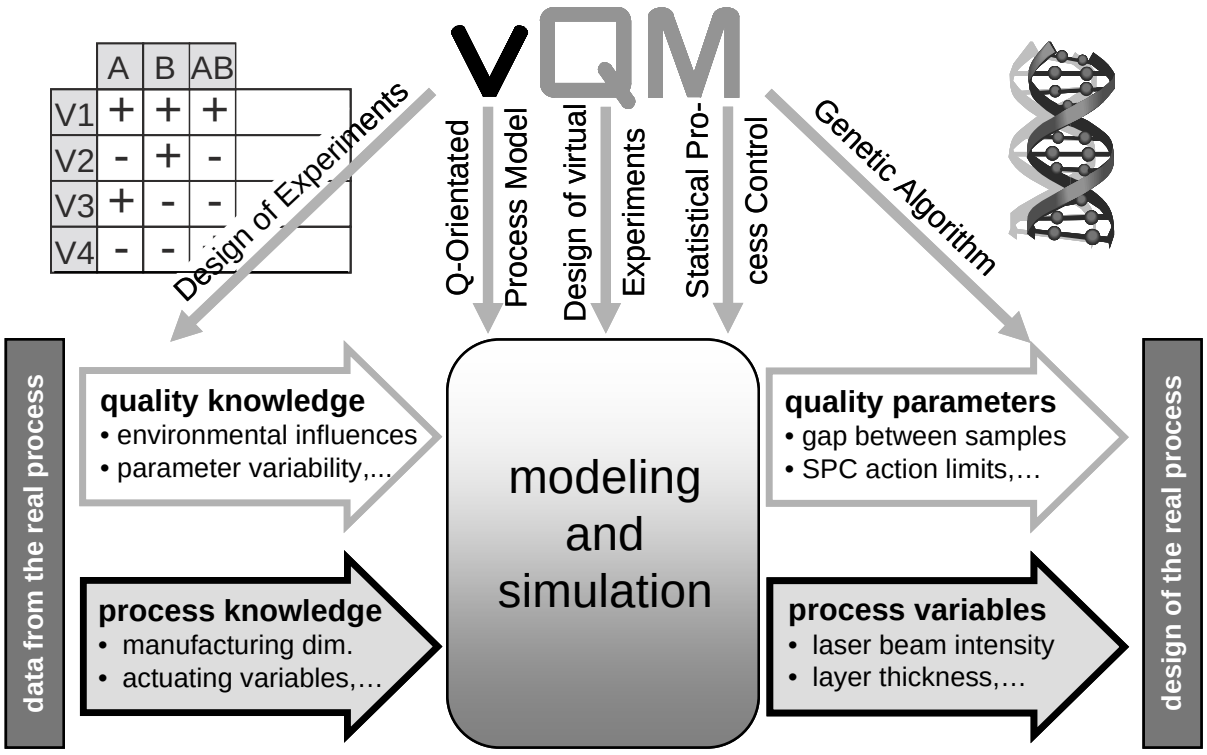

Figure 2: Elements of the Virtual Quality Management

The designed Quality Orientated Process Models can be used in the process development in two different ways:

On the one hand process chains can be tested and optimized virtually: This means that cost and time intensive test runs can be done by use of the simulation model in a fraction of the time that would be necessary in real tests. Moreover, the manageable sample size in simulation studies can be factor 100+ higher than in the "real world", because it only requires more calculating time and the real production line can produce its parts undisturbed.

On the other hand it is possible to test and optimize quality techniques before the process has been realized. Multiple prognoses about the quality capability of the measurement system, the machine or the process can be performed and the results bear the potential to detect weaknesses in the process chain concept. This information allows initiating necessary changes in a very early stage, when the costs for changes are still relatively low. Furthermore, quality techniques to supervise real processes can be set up, tested and optimized virtually, so that quality control cycles have already proved their liability in a virtual production trial before being integrated in the real process. Hereby an unopposed and undelayed production start-up can be assured and quality techniques like quality control charts - which were reserved for high volume runs up to now - become economically interesting for "middle volume runs".

Process models have been separated in three categories in order to divide the different use cases strictly: Ideal Models, Quality Orientated Process Models and Quality Supervised Process Models. In figure 3 the connections between the diverse process models are described.

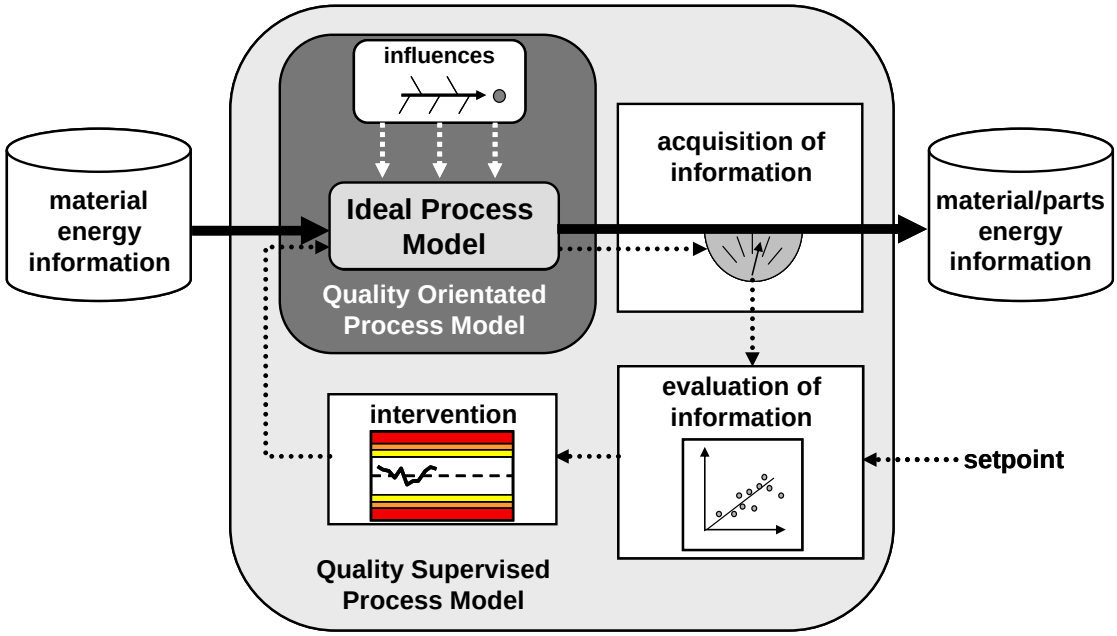

Figure 3: Connection between the diverse process models

By use of Quality Orientated Process Models much more extensive studies can be realized as it was before: The Design of Experiments shall be used for the data collection on the basis of simulation models to ensure a time-efficient progress. Thus some adjustments of this method are necessary, which has to be enlarged and modified to the Design of **virtual** Experiments.

But no statements about the quality capability of the process can be made solely by use of Quality Orientated Process Models. Therefore the process model has to be upgraded to a

Quality Supervised Process Model. An enclosed control cycle is not necessary for the execution of a machine or a process capability analysis. But if i.e. the parameters of a quality control chart shall be defined and evaluated, extensive modifications are required, which reach from the virtual extraction of samples to the self-acting intervention of the program in the simulated manufacturing process (figure 3). Control cycles can be designed depending on these studies, i.e. by use of the Statistical Process Control (SPC), evaluated and optimized through Genetic Algorithms.

3 Guide to the Assembly of Quality Orientated Process Models

For efficient use of Virtual Quality Management, detailed process models are necessary in a (process) simulation software. But due to the correlation between the accuracy of the process model and its complexity, the user has to be supported, so that he can handle the complexity (Weckenmann, 2008). Thus guidelines were conceived which separate the acquisition of information and the modeling in manageable partial stages and support these stages by fitting quality management techniques:

Based on different approaches for the execution of real projects in the "Design for SixSigma"-methodology (Bergbauer, 2004) a system was sought, which can be assigned for the assembling of Quality Orientated Process Model in simulation software. So the guideline is based on the DMADV-scheme (Define-Measure-Analyze-Design-Verify) (Reissiger, 2007), which is also derived from the well known DMAIC-circle (Define-Measure-Analyze-Improve-Control). As the DMAIC-circle is known as an established tool for optimizing already existing processes, the DMADV-scheme is used considerably earlier in the product-life cycle for the creation of error-free products and processes. Figure 4 shows the connection between DMADV and DMAIC:

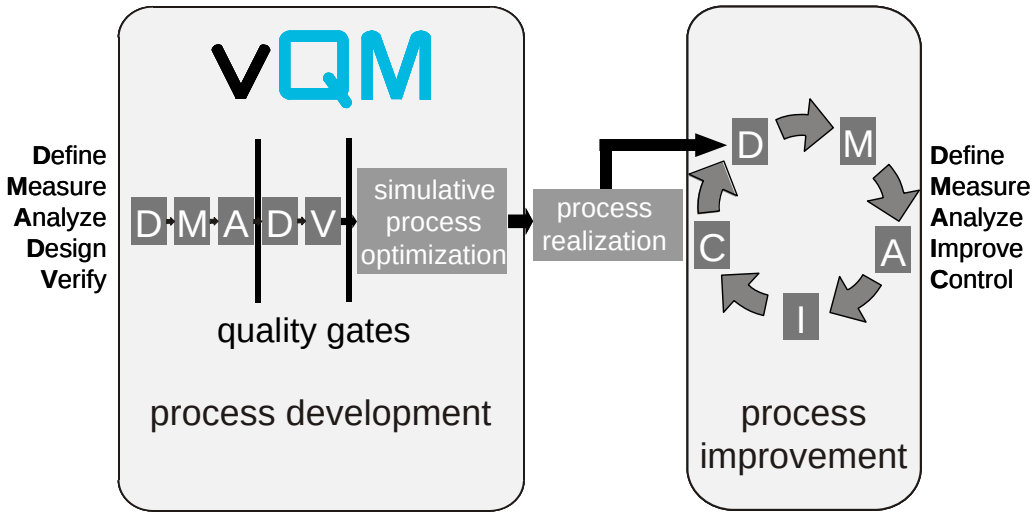

Figure 4: Interrelation between DMADV, DMAIC and vQM

Within the Virtual Quality Management the design of a real process by use of DMADV equals to the mockup of a virtual (simulative) one. A short overview of the single phases with their special specifications for the creation of Quality Orientated Process Models will be given on the following pages. Selected quality techniques for the support of every single stage are recommended within these guidelines. See figure 5 for an overview of the guidelines.

Define

The relevant general conditions for the creation of the process model are determined in the define-phase. Parts of the framework are the duration and the goals of the project, the resources of available staff, material and finances, as well as the specification of the particular model. These specifications contain especially the definition of the process to be represented, alternatively the process-chain with its particular dependent variables, the process-boarders and the determination of the accuracy of the mockup. In this context it is essential to keep the target-orientation up and to define reasonable bounds. It is very important, especially by illustrating cutting-edge process-models with marginal background knowledge, to engage help of the development department already in this early phase.

To describe a process in vQM SIPOC-Charts (Supplier-Input-Process-Output-Customer) are used, which are closely related to the flow-chart method (Reissiger, 2007). By using such simple process-illustration tools in this very early stage, the results can be carried forward in a structured form to the next phase and the loss of the focus on the process goals can be avoided.

A very important part of the design-phase is the definition of the test-environment:

- parameters and functional connections to be checked,
- range of values to be tested,
- gap between two measuring points,
- general conditions for the whole experimental design,
- etc.

Furthermore, it has to be assured, that necessary data from the real process are - as far as possible - available at the point of testing, to compare real and simulated results. Otherwise precious time will be lost or the accuracy of the simulated model cannot be determined.

All information, which was brought together, has to be recorded in a Project Chart; this document has to be detailed and actualized during the project (Lunau, 2007). It is the central instrument for the project director to manage the task.

Measure

The content of the measure-phase is by far larger than just “measuring”: With the general conditions set, all significant pieces of information have to be collected, which are required to create the process model. Three ways of knowledge acquisition have to be considered at that point and should be used in exactly that order: literature research, questioning experts and carrying out real test runs. Literature research in libraries, databases and the internet often gives a general survey of the process which has to be designed as well as the relevant interactions between environmental influences as well as control- and target-variables. This preliminary work is necessary to reduce time-consuming meetings with experts and extensive test runs to a minimum. An Ishikawa-diagram can help to visualize the interactions. If this illustration is filled with the existing pieces of information, it is considered to be a solid base for a brain trust to check the already detected parameters critically and add missing aspects.

As real test runs are very often closely connected with an enormous effort of time and money, they should only be used very rarely as last choice. The tools of statistic test methodology can be quite helpful for the user, which are chosen and used according to the particular precognition.

Analyze

The acquired data are going to be interpreted in the analyze-phase and proceed into a concept for the model creation. This phase is determining what kind of input parameters, environmental influences and interactions are significant and need to be considered.

In addition to that a raw concept of the simulation model is being acquired: it is of extraordinary importance to divide the process or the process chain into reasonable units as well as to define their functions and interfaces to other sub processes. With this approach, valuable resources can be saved, e.g. the performance of programmers and process engineers. This happens mainly by the minimization of the number of iteration loops, which are normally caused by vague job definitions at the design of the processes.

The concept for every single process unit has to be described in a standardized form, called Modeling Key Document. It contains information about the position in the overall process model, the responsible people in the project, a short textual description, the functional interrelations, which have to be implemented, the interfaces between the modules and the specific testing restrictions for the single module.

In order to move on after this phase, a quality gate must be overcome. When all relevant pieces of information have been collected and have been transferred into a modeling concept, it is reasonable to present these results to a brain trust. If relevant facts are missing or falsely incorporated in the simulation model, changes can be made with a justifiable effort. The extra work to implement modifications at a later point in the modeling process increases strongly in complex simulation models. Here the well known Rule-of-Ten for failure costs can be used as a guideline. It says that costs for correcting errors increase by the factor of 10 per step in the product development process (Linß, 2005).

Design

After a brain trust has approved the model concept, the conversion into a simulation model is the next step. By structuring the process, it is very easy to divide the job up to several people. As the sub units are independent and only connected with other modules by their interfaces defined in the Analyze-phase, they can be built up separately and be composed to a complete Quality Orientated Process Model in the end. By establishing several sub units side by side, the absolute time for the completion is being reduced considerably in the spirit of "Simultaneous Engineering". With a gapless documentation it is possible to ensure that colleagues can understand the work reciprocatively in order to replace each other, if i.e. someone gets sick.

It is important to test the single modules at first separately in a test environment for their operational reliability, before the implementation into the overall model takes place. This procedure reduces the troubleshooting in the overall model to an absolute minimum, which mostly lies in problems with the interfaces between the diverse modules.

Verify

Before the quality oriented process model can be used for information retrieval or for the solution of optimization problems, it has to be validated. Ideally process parameter combinations and ambience parameter combinations are being tested in real test runs and the

same way in simulation models. Once again the tools of the Design of Experiments are being used to reduce the effort in validating.

The comparison of the results from real test runs and simulation studies allows explicit conclusions about the accuracy of the simulation model. Should the accuracy not be reached, which was determined in the define-phase, the process has to be tested again and the model has to be extended by additional parameters and their interactions. Only if the model passes this quality gate, it is recommended to use this model for further simulation studies, on which sometimes "expensive" decisions are made.

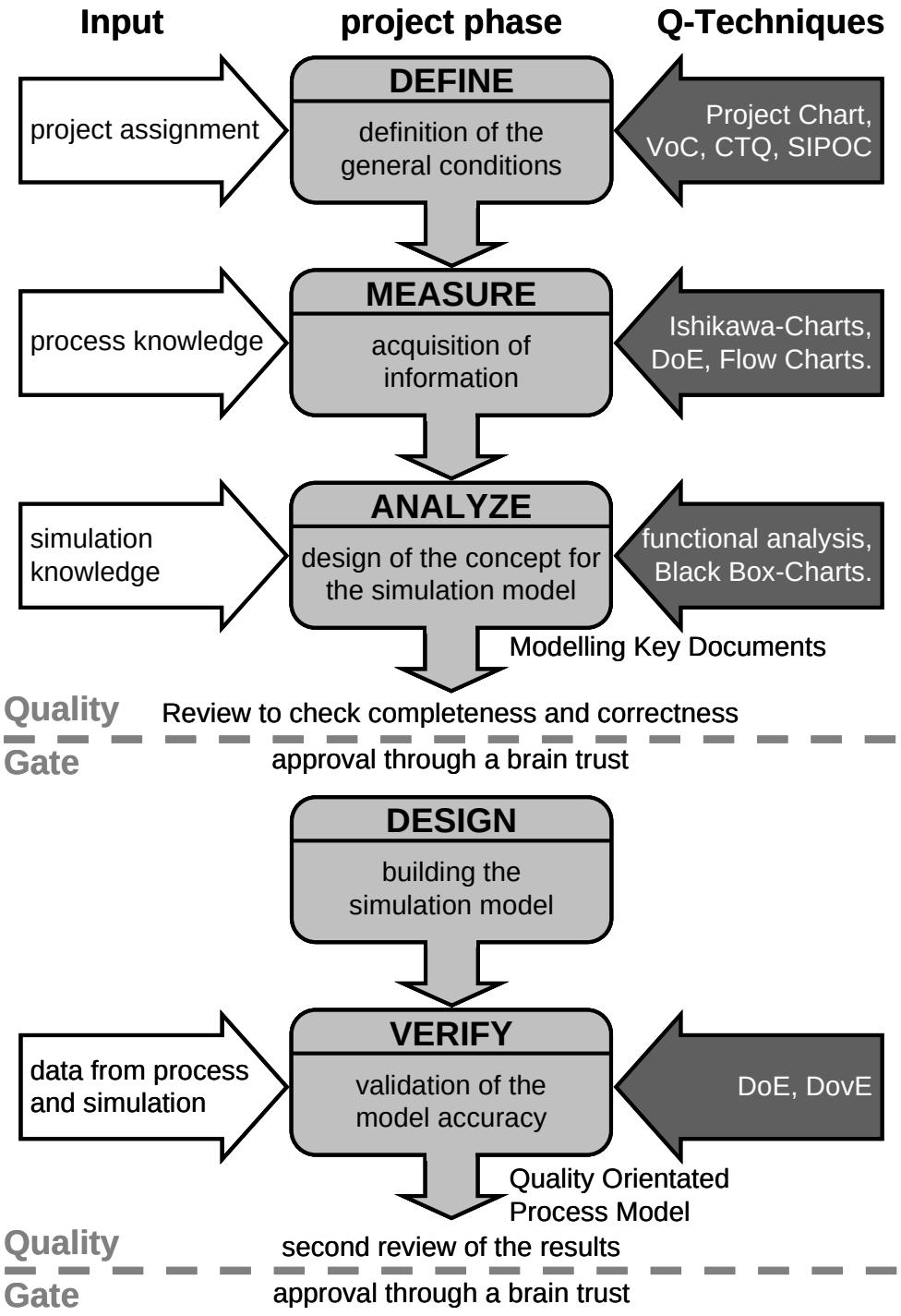

Figure 5: Overview of the guidelines

The guidelines have been tested and optimized intensively by setting up the model of a stereolithography process. Now there is a model available, which forecasts selected process parameters with an accuracy of more than 99 percent according to the variation of environmental influences. This model is the base for other studies and researches in the future.

4 Summary and perspective

The potential of simulation-based information retrieval out of process models is currently not fully tapped by far! The common disregard of environmental influences and imperfectnesses of the process in order to reduce the complexity of the simulation model leads to "Ideal-Models", with which only insufficient conclusions about the quality capability of the process can be drawn. The Virtual Quality Management offers tools from the modeling up to the optimization of quality control cycles, which can and shall be used in the planning stage of a process.

The guidelines for the systematic and efficient set up of Quality Orientated Process Models have been exemplified. First of all the widening of "Ideal-Models" to Quality Orientated and Quality Supervised Process Models has to be mentioned, which leads to a holistic reproduction of the process in simulation models and the increase of the reliability in real processes.

Currently, flexible function-modules for machine and process capability analyses are under construction. Moreover Quality Orientated Process Models will be enlarged by a module, which completes a quality control cycle by the simulation of Shewhart-Quality Control Charts and adequate intervention strategies. It will also soon be possible to optimize the parameters of these control charts by generic algorithms automatically.

The "Design of Experiments"-methodology will be enlarged and adapted for the new application area "simulation". Therefore the specific requirements of simulation programs as well as advantages and disadvantages of simulation studies have to be analyzed, to maximize the benefit and balance the weaknesses. Afterwards the "Design of virtual Experiments"-toolbox has to be set up, to support the user by recommending corresponding quality techniques and by offering specific simulation modules to work off user-defined or automatically-created experimental designs.

5 List of references

(Bergbauer, 2004)

Bergbauer, A., (2004), *Six Sigma in der Praxis: Das Programm für nachhaltige Prozessverbesserungen und Ertragssteigerungen*, Expert Verlag, Renningen, Germany

(Kamiske, 2008)

Kamiske, G., Brauer, J.-P., (2008), *Qualitätsmanagement von A bis Z - Erläuterungen moderner Begriffe des Qualitätsmanagements*, Carl Hanser Verlag, Munich, Germany

(Linß, 2005)

Linß, G., (2005), *Qualitätsmanagement für Ingenieure*, Fachbuchverlag Leipzig in Carl Hanser Verlag, Munich, Germany

(Lunau, 2007)

Lunau, S., (2007), *Design for Six Sigma + Lean Toolset - Innovationen erfolgreich realisieren*, Springer Verlag, Berlin, Germany

(Reissinger, 2007)

Reißinger, W., Voigt, T., Schmitt, R., (2007), "Six Sigma", Pfeifer, T., Schmitt, R., *Masing - Handbuch Qualitätsmanagement*. Carl Hanser Verlag, Munich, Germany

(Weckenmann, 2008)

Weckenmann, A.; Bookjans, M. et al., (2008) "Virtuelles Qualitätsmanagement", Goch, G., *Innovationsqualität: Qualitätsmanagement für Innovationen. Bericht zur GQW-Jahrestagung 2008*, Shaker Verlag, Aachen, Germany

(Weigert, 2002)

Weigert, G.; Werner, S.; Kellner, M., (2002), "Fertigungsplanung durch prozessbegleitende Simulation", Aachener Werkzeugmaschinenkolloquium (AWK), *Wettbewerbsfaktor Produktionstechnik*, Shaker Verlag, Aachen, Germany

6 Acknowledgment

The authors would like to thank the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), which made the research of this extraordinary interesting topic possible by funding the collaborative research centre 694 ´Integration of Electronic Components into Mobile Systems´.