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FREQUENCY MAPPING FOR ROBUST AND STABLE PRODUCTION SYSTEMS

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ABSTRACT

Characterized by a complex network of interwoven tasks, time delays, iterations, and rework caused by problems and changes of customer specifications product realization processes are highly dynamic systems. Applying control engineering methods to product realization processes in order to treat its dynamic behaviour can bring a significant benefit for the quality management of these processes. Using its metrics and terms the paper discusses the assignability of the field of control theory for the analysis and design of organizational production processes and order fulfilment. Furthermore it provides an approach towards a description model for quality control loops. Mapping a production system within the frequency domain will facilitate the setup of required control loops and the configuration of a stable and robust production system.

KEYWORDS

Quality Management, product realization, control engineering, discrete state space

1. INTRODUCTION

The environment of enterprises stays turbulent: Manufacturing enterprises are influenced by multiple dynamic external factors such as the individualization of products, the acceleration of product life cycles or the pace of technical innovations. Moreover dynamic internal business factors such as the capability of processes, the utilization of resources, or the qualification and capability of employees have a significant influence on companies’ normative, strategic, and tactical orientation. Therefore, manufacturing enterprises have to handle the growing variety and dynamics from internal and external sources (Schmitt and Beaujean, 2009). Nevertheless companies cannot allow the effort to plan all probable states of their production systems or to invest in costly activities like fire fighting or specialized task forces to cope with the consequences of these internal and external dynamics (Jovane, 2009).

Considering these rising organizational and technological challenges the field of quality management has to answer the questions how the described dynamics can be handled on strategic, tactical and operative levels. As an integrative approach quality management models have to support the decision processes of enterprises crossing the different hierarchical levels and company internal boundaries between departments or divisions. Therefore quality management empowers enterprises to identify their desired steady state equilibrium and provides the principles, methods and tools to develop enterprises towards this ideal point or stabilize it within the equilibrium.

2. SEEKING FOR ROBUSTNESS AND STABILITY – A NEW UNDERSTANDING OF QUALITY

Based on the characterizing terms for the performance measurement dimensions of production systems, a framework of a quality management model has to define and analyze the challenges of markets and customers and while also considering the strategic objectives, the entrepreneurial conditions and the corporate skills.

Nowadays the design of the operations and processes are often based on management and quality concepts which are heavily influenced by various philosophies, concepts and methods such as Total Quality Management (TQM), Lean Management, and Six Sigma. Moreover existing explaining and evaluating models like the DIN ISO 9000:2005 series, or evaluating models like the EFQM Model are well known and widely spread throughout various industries strongly interlocked with the principles, concepts and methods of these philosophies.

Fulfilling the characteristics of an explanation model the EFQM Model measures for example the current state of maturity of operations based on a strong statement about the cause and response chain of successful enterprises: Excellent companies provide the leadership to build strategies which incorporate people, partnerships and resources, implementing and operating efficient and effective processes, products and services in order to satisfy the stakeholders and gain extraordinary financial results.

How do these models encounter the rising and central questions of companies about a stable equilibrium in rapid changing, dynamic environments, as a guarantor for competitiveness and viability? Can these models help companies to align their strategies, structure, and operations towards the desired equilibrium?

Both models, the EFQM and the DIN ISO 9001:2007, have in common that they emphasize on the increase of the overlap rate of customer demands and product features (Gucanin, 2003) as the target equilibrium (figure 1).

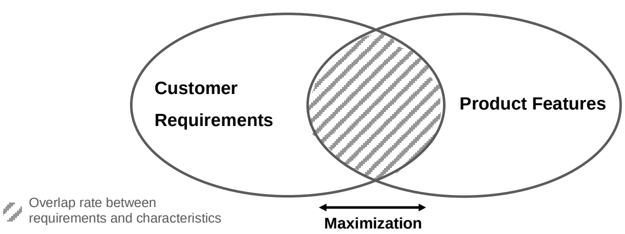

Figure 1 – Quality Management as a maximization problem

Accordingly, the models proclaim the optimization of the overlap of customer demands and product features as a maximization problem. But are companies really able to align their strategies to a one-dimensional maximization problem? The analysis of this optimization problem shows that the complexity of the desired equilibrium was reduced using different implicit restrictions. With each target field of the traditional quality understanding – the customer demands and product features – two main restrictions were implied:

- Restriction 1 – Organizational-sided assumption: The companies' possess all the skills to operate exactly as their strategies dictates
- Restriction 2 – Market-sided assumption: Companies already knew or decided who their customers are

Many times the entrepreneurial praxis has proven these implicit assumptions as too restrictive. Especially in high-wage countries companies which produce within the given definition of quality, delivering high quality products and running both effective and efficient processes, are increasingly suppressed and substituted by competitors of low wage countries (Tseng, 2003). Hence, the pure adherence to the traditional quality understanding does not cause economic and entrepreneurial success. Therefore enterprises cannot trust in unidirectional maximization of its quality target parameters, but have to balance their position within the target field considering conflicting target parameters.

Due to their primarily value-adding-oriented view of the process, the quality management models are further lacking to give information about how a company can identify and therefore has to align to reach the aforementioned desired equilibrium. Meanwhile the models cannot provide answers about how to establish the needed feedback mechanisms in order to institutionalize organizational learning and the dampening of oscillations caused by disturbances.

The philosophy of entrepreneurial quality management attempts to close these gaps and ameliorate existing quality management models. Instead of the traditional maximization problem of customer demands and product features, a new model has to allow companies to and identify targets and balance them towards their desired equilibrium. The management model is built on the entrepreneurial quality philosophy which disperses the one-dimensional focus and breaks the given restrictions open.

To start with, Restriction 1 assumed that the operations are able to produce the exact product characteristics which the management dictates. In order to relax this situation the field of product features must be advanced towards a higher resolution. This is achieved by the consideration of corporate orientation and the corporate skills.

Simultaneously the remaining market-sided constraint assuming that the company already knows the targeted customers is dissolved since the customer requirements stay as the counterpart to the organizational characteristics. Figure 2 shows the triangle of the Entrepreneurial Quality Philosophy.

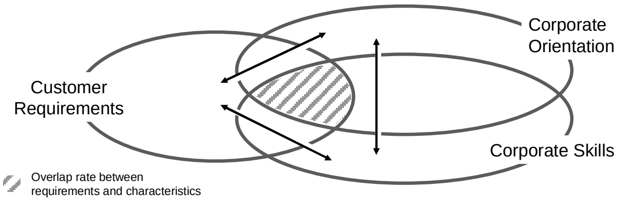

Figure 2 – The Entrepreneurial Quality Philosophy

After the introduction of the entrepreneurial quality management philosophy these elements must be incorporated in a framework which enables companies to design their structures, operations, and mechanisms in order to reach the desired equilibrium of entrepreneurial quality.

3. THE AACHEN QUALITY MANAGEMENT MODEL

The Aachen Quality Management Model shown in figure 3 was designed to meet this need. It provides a scope of action, which allows the design of entrepreneurial quality management for a company by considering strategic objectives, entrepreneurial conditions, resources and product life cycles (Schmitt, 2007). The constituting elements of the Aachen Quality Management Model are Market, Management, Quality Stream and Resources & Services.

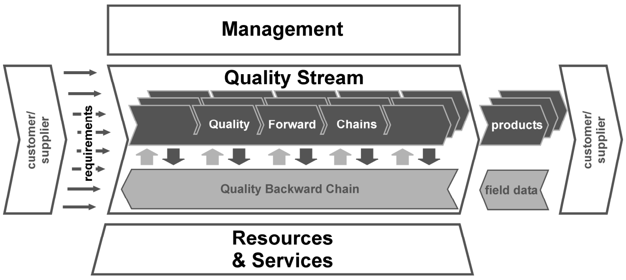

Figure 3 – The Aachen quality management model

The unique outline of the Quality Stream consists of two structural elements: the Quality Forward Chains and the Quality Backward Chain.

The Quality Forward Chains take credit to the proactive and preventive measures per product group and life cycle such as quality gates in the product development process. Therefore they cannot just be interpreted as the value creation processes, but also reflect the different states of the products within the product development and production processes.

The Quality Backward Chain works as the central feedback mechanism organizing reactive and corrective actions for all processes and product groups. As stated before, the functioning of each mechanism requires a closed loop feedback mechanisms, where the system states are continuously planned, monitored and adapted from the view of the relevant perspective. Building integrated and cascading quality control loops the proper cooperation of the Quality Forward Chains and the Quality Backward Chain is the central prerequisite for the functionality of the stability within the field of Entrepreneurial Quality.

The notion of Entrepreneurial Quality, stability and robustness within the Aachen Quality Management Model can be used to derivate further models as for example the redesign of process and project landscapes within product realization (Schmitt, 2008). In the following paragraphs a model targeting the balanced design between corporate orientation and skills by frequency mapping will be presented.

4. TODAYS CHALLENGES FOR THE STABILIZATION IN PRODUCT REALIZATION

Within the quality stream and the Quality Forward Chains the product realization processes combine the major business processes of producing companies – innovation, product development and production – containing many of the companies' core competencies. Besides the rising technical complexity of products three main drivers for disturbances for the management of product realization processes are frequently discussed in literature and also within companies (figure 4):

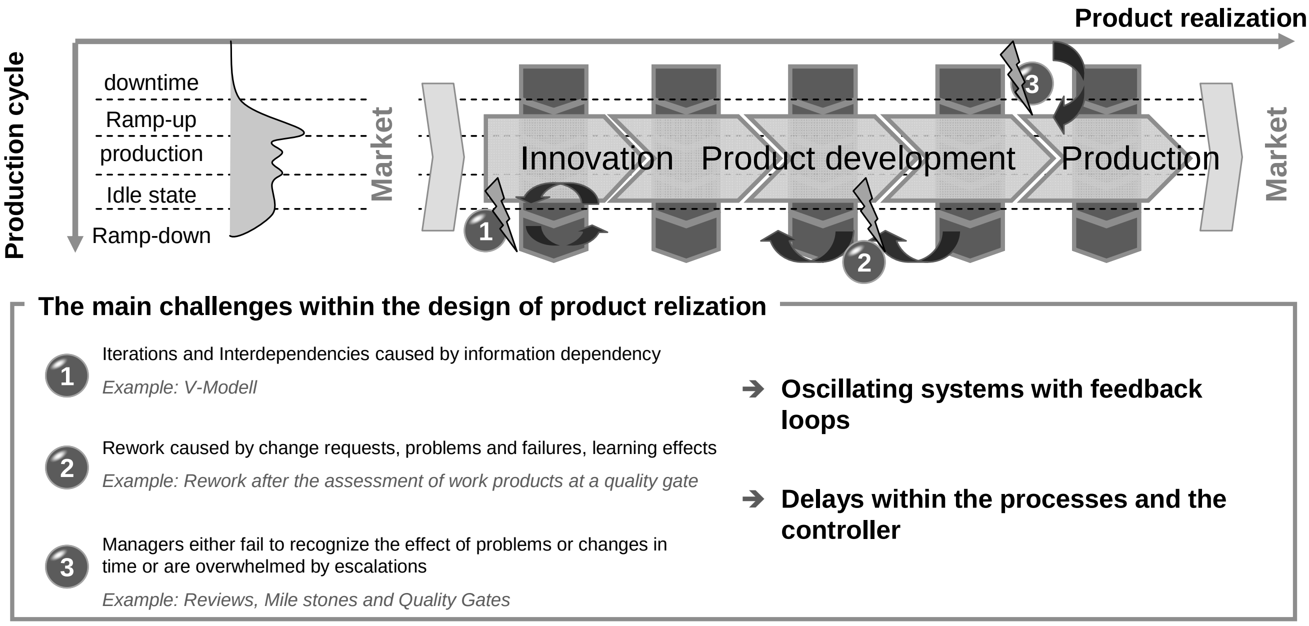

Figure 4 – Challenges within product realization and production cycles according to Heinen

- All processes phases of product realization are characterized by iterations and information dependencies. The dependency between different activities or tasks is especially known within innovation and product development processes where activities need a degree of information from other activities in order to be initialised. Example for this effect is the development according to concurrent engineering or development activities within the V-model. The permanent communication endangers the occurrence of oscillations considering the work progress (Browning and Ramasesh 2007).
- Rework caused by change requests of the customer, learning effects and iterations especially during the product development, and both problems and failures during development and production amplify the dynamic effects (Eppinger et al, 1994).
- Moreover managers of product realization processes either recognize problems late risking the violation of the product or project targets or tend to be overwhelmed by the controlling work due to frequent audits, assessments or reviews. Hence, not only the iterations and rework cycles of the processes, but also the corrective measures of the managers are distinguished by time delays (Schmitt, 2010).

Out of the perspective of systems theory product realization processes are high dynamic systems characterized by feedback links between activities and time delays within the controlled processes and the impact of the controller itself.

5. TOWARDS A MODEL FOR THE ROBUST DESIGN OF PRODUCT REALIZATION

Increased performance of realization processes in terms of time-to-market, productivity and costs can be achieved by focussing both structural design and control policy of realization processes; principal tasks of modern quality management.

The model contains three sectors reaching from the illustration of the product realization with the help of a process reference model, over the identification of the critical elements for the evaluation of the robustness of the product realization towards the frequency mapping which allows the simulation of different management policies assessing the stability of the different controller conditions (figure 5).

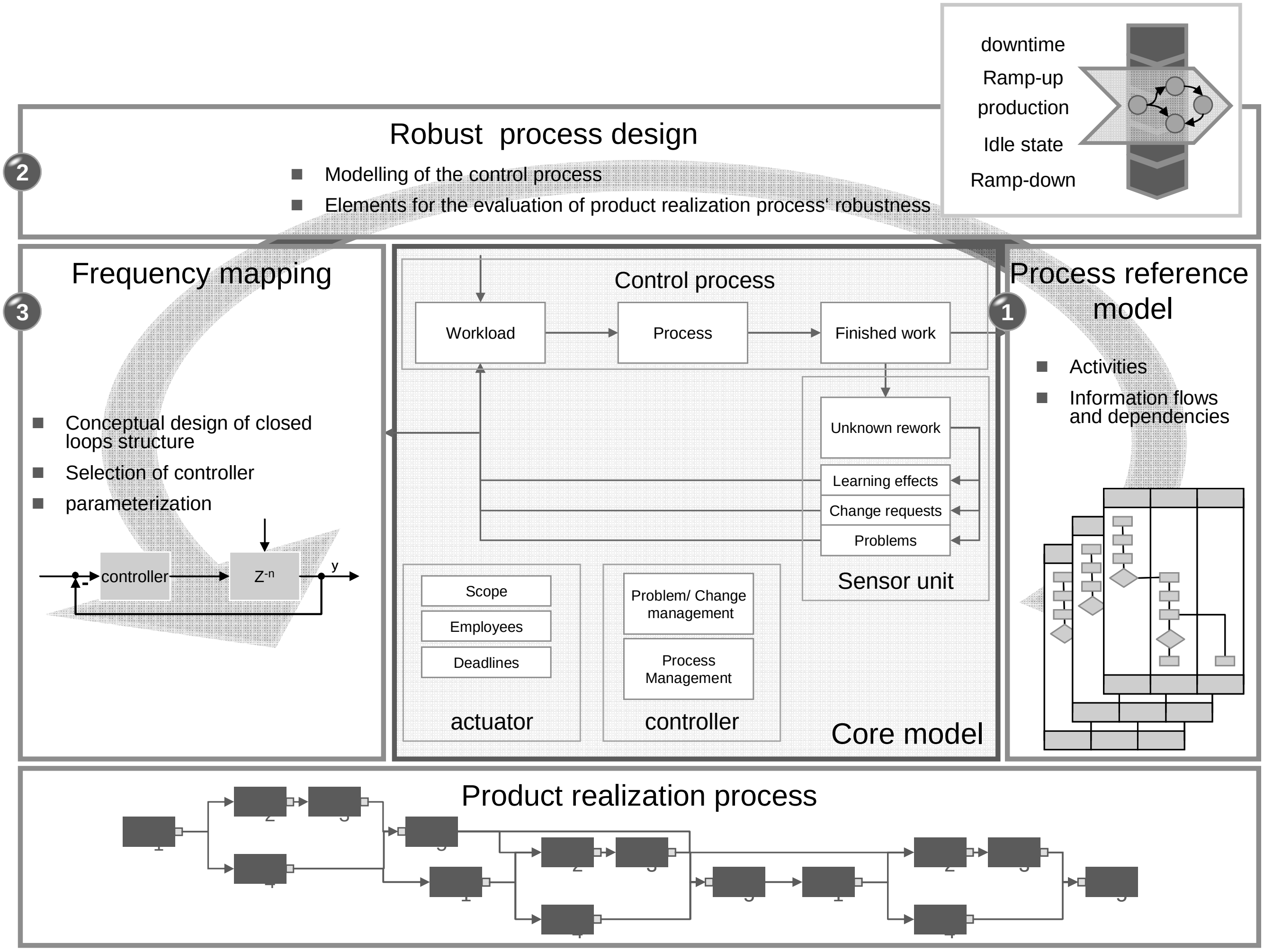

Figure 5 – Maximum dimensions for wider (double column) tables and figure

While the first subsection of chapter 5 will explain the core of the model which are linked to all three sectors the following subsection will give an introduction to each subsection.

5.1. THE CORE MODEL

Each sector inherits parts of the structure or systematic of the core model. Thereby the interfaces of all sectors and the proper transmission of the parameters and structures between the sectors can be easily secured.
The core model has both, structural and systemic design components.

5.1.2. The structural model component

The structural model is deviated from the basic architecture of control loops in control engineering. According to the definition of control loops a quality loop contains besides the controlled process three major stages, each executing a part of the quality control process: the “Sensor unit”, the “Control Unit”, and the “Actuator Unit” (figure 7).

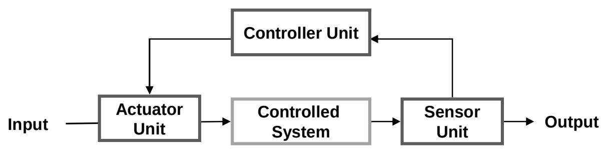

Figure 6 – Architecture of an elementary control loop

Sensor unit

The main assignment of the sensor unit is to monitor and inform the controller about the current state of the system. All control units are assumed to work in discrete state space assuming that a constant monitoring of the process is impossible, but restricting the function of the control elements always within equidistant time spots. Hence the frequency of the signal is constant and does not depend on a defined event. Examples of quality sensors are: reports from factory workers, defect detection during QA spot tests, customer complaints, or new issues discovered while resolving known problems.

Control unit

The main task of the control stage is the selection of measures and management policies changing and adapting the controlled system. In the context of the quality control system, the selection or development of an effective solution for a given issue alone is however not sufficient.

Actuator unit

The implementation of the measure is the main function of the actuator. It has to locate the exact stage for the measure initiation within the forward chains, deciding the scope, speed and costs of the implementation. Examples for measures are: adjustments scope in product development, staff headcount, or postponement of deadlines. Additionally the actuator stage is responsible for providing the means of evaluating of measure success.

5.1.2. The systemic model component

But, for control theoretical methods like the frequency mapping of product realization, which is a quantifiable approach of stability analysis also systemic and quantitative components need to be defined. As for one of the early steps of each analysis and design project in control engineering a control variable has to be identified (Lunze, 2007). A quantifiable variable is needed which comprehends to the process and product quality of the system and can give a measure of the dynamics in product realization. The recommended measure for the status and quality of product realization processes is the amount of checked and released tasks or work products per period which plays also a significant role within the rework cycle model known in system dynamics (Cooper and Kenneth, 1980). The model compares the amount of tasks to be done set by the management with the amount of tasks completed, checked and release. The difference between these values, the control deviation, depicts the necessary rework increasing the inventory or tasks to be done. Hence the sensor has the function to check and release or deny the work products of the tasks. The manager can affect the proportion of released and open tasks by e.g. increasing the staff, or changing the project scope.

The structural and systemic components are used by the three model sectors, reference process description, robust process analysis and frequency control.

5.2. DESCRIPTION OF A PROCESS REFERENCE MODEL

According to ROSEMANN the main objective of a reference model is "to streamline the design of enterprise-individual (particular) models by providing a generic solution" (Rosemann, 2003). Hence reference models are blueprints of best practice, which accelerate the modelling of individual processes by providing a set of potentially relevant processes and structures.

The process reference model inherits the structure of the quality loops from the core model. Therefore the model contains a reference description of a production realization process, and the process steps of the sensor, controller and actuator units of the quality control loops. Its process view defines the integrated monitoring and processing of failures, problems and change requests and channels the information towards the controller which maintains the management of the product realization process. Within the actuator the management policies for countermeasures are defined.

It also captures the information network such as information flows, process dependencies and interfaces between roles, responsibilities and ICT solutions supporting the processes or quality loop units.

The reference model can be easily adapted to product realization processes and the control loops of different companies allowing gathering all the necessary information for the analysis of robustness and stability in the frequency mapping sector.

5.3. ROBUST PROCESS ANALYSIS

In control engineering systems are called robust if the control variables show the desired behavior even if system's parameters shift significantly. In quality management TAGUCHI introduced a well known method for robust design. Similar to control engineering robustness is defined as the insensitivity of products, processes and systems to noise. With the signal-to-noise ratio TAGUCHI defines a method to quantify the robustness.

The robust process analysis uses a similar approach. It assesses the robustness of the product realization processes according to the tailored process reference model. To give an example the connectivity between the tasks is one important measure for the robustness of the process. It takes the tasks running parallel to one task in the sense of concurrent engineering permanently exchanging work products into account. Moreover the number of tasks affected by the rework in one task gives another important measure to the robustness level. Information breaks due to system interfaces and transmission between roles and responsibilities allow also inference to the robustness of the tasks.

5.4. TIME DESCRETE CONTROL MODEL FOR FREQUENCY MAPPING

When Toyota introduced takt time as the central element for the synchronization of its production system the design state space for production systems shifted from the planning of processes in time domain to the frequency domain. This method is well known to control engineering which transfers complicated differential equation in time domain via Laplace Transformation to frequency domain where the system can be setup easily following simple mathematical rules. The methodology of frequency follows this fundamental idea.

From a system engineering viewpoint the product realization process contains a series of connected inventories with internal precedence relationships. The inventories are the tasks or work products checked and released of the product realization process or a single phase waiting for the further processing. All quality control loop elements, the sensor for the detection of unfinished, incorrect tasks or tasks affected by change requests are characterized by time delays endangering the stability of the product realization system. Describing the model in time discrete state space takes credit to these delays for an easier analysis and design of the controller and control parameters. The analyzed robustness of the process elements is contributed within the parameter set in the model. The z-Transformation of the resulting difference equations makes the analysis of the systems behaviour within frequency domain possible.

6. CONCLUSIONS

Quality management has to give answers to companies acting in markets characterized by changes and increasing competition. Hence, the restriction of traditional philosophy of quality management as a maximization problem has to be resolved towards an entrepreneurial understanding of quality management as a stabilization problem.

A core element of companies in order to cope with change and disturbances in business processes like product realization are feedback mechanisms. The structure and conduct of a quality control loop model can stabilize realization processes by dampening oscillations caused by iterations, rework and changes. The three sectors of the illustrated model take account structural and systemic aspects of product realization processes leading to the methodology of frequency mapping in order to define stable work points. The further research will challenge the development of robust process analysis and frequency mapping and evaluate the model in companies' environments.

7. ACKNOWLEDGMENTS

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