Viharos, Zs. J.; Monostori, L.; Schmitt, R.; Glöckner, H.; Stiller, S.; Markos, S.: Quantifiable Closed Quality Control (QC2), Factory Automation 2011 Conference, 25-26. May, 2011, Győr, Hungary, ISBN: 978-963-7175-3, pp. 25-33.

Quantifiable Closed Quality Control (QC^2)

Zsolt János Viharos[1], László Monostori[1,2], R. Schmitt[3], H. Glöckner[4], S.Stiller[5], Sándor Markos[6,2]

[1]Fraunhofer Project Center on Production Management and Informatics, MTA SZTAKI, Budapest, Hungary

[1]zsolt.viharos@sztaki.hu

[2]Department of Manufacturing Science and Technology, Budapest University of Technology and Economics

[1,2]laszlo.monostori@sztaki.hu

[3]Laboratory for Machine Tools and Production Engineering WZL, RWTH Aachen University, Steinbachstr. 19, 52074 Aachen, Germany

[3]r.schmitt@wzl.rwth-aachend.de

[4]h.gloeckner@wzl.rwth-aachend.de

[5]s.stiller@wzl.rwth-aachend.de

[6]Hungarian Tool Maker's Association, SZMSZ, Budapest, Hungary

[6]markos@manuf.bme.hu

Abstract: To meet the challenge of producing innovative and technologically demanding products economically, companies need the ability of quick and flexible reaction to internal and external disturbances. As a result the companies' objective shifts from maximization of quality to a "controlled quality" aiming for the stabilization of the operative and strategic value creation process. So the main problem of manufacturing enterprises is to dampen the oscillation of product, process and system quality caused by impacting disturbances and ineffective activities and measures due to fuzzy or uncertain information. The paper proposes a new approach for the evaluation of the quality of entrepreneurial control mechanisms within production systems. . Using the metrics and terms of control theory and cybernetics the organizational feedback processes can be developed further towards a blueprint for generic closed quality control loops. The reference process description of the quality control loop is the basis for the further examination and feedback mechanisms, where the behavior of quality loops is designed regarding the operational stability as the main performance indicator. Assisted by this methodology companies are able to identify and design their quality control loops.

Key-Words: Quality Control Loop, Quality Management, Closed Loop Quality Control, Control Theory

1 Introduction

To meet the challenge of producing innovative and technologically demanding products economically, companies need the ability of quick and flexible reaction to internal and external disturbances [1]. Increased performance of a company can be achieved by focusing on improvements to effectiveness and efficiency; principal tasks of modern quality management. As a result the companies' objective shifts from maximization of quality to a "controlled quality" aiming for the stabilization of the operative and strategic value creation process. So the main problem of manufacturing enterprises is to dampen the oscillation of product, process and system quality caused by impacting disturbances and ineffective activities and measures due to fuzzy or uncertain information [2].

2 Quality Control Loops

The dynamic character of business processes demand the implementation of closed quality control loops to prevent a chaotic development and instable behavior in case of disturbances.

To control the quality of a process efficiently, three main stages are necessary - the sensor unit, the control unit and the actuator unit [3, 4]. The general structure and the assigned tasks of a quality control loop are based on the DIN standard 19226 (Fig. 1) and extended by main principles of management cybernetics and failure management [5]. The diversity of business processes requires the interpretation of control theory in a much broader sense.

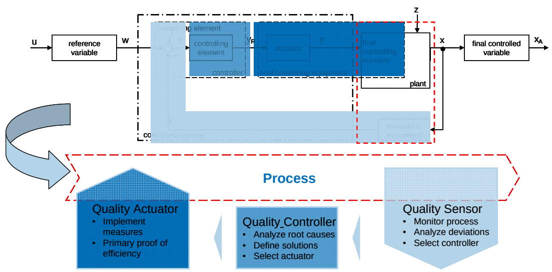

Fig. 1: Derivation of closed loop quality control

2.1 Quality Sensor

The first main task of the quality sensor is to collect raw quality data from various stages of the controlled system. The distribution of acquired data by the acquisition unit of a sensor is either constant with a defined frequency (e.g. KPI reporting) or event-driven.

For the detection of deviations from a defined process quality target, raw quality data needs to be filtered, prepared and reduced. Finally an adequate quality controller has to be selected and informed, based on the analyzed data and the identified problem.

2.2 Quality Controller

The quality controller develops and selects adequate measures based on the information provided by the quality sensor. The quality controller can access a database of existing measures as well as develop completely new solutions.

For a closed action flow and stable system behavior, escalation routines, timing parameters and well designed sets of standardized measures have to be defined. The selected solution has to be reported to an appropriate quality actuator together with time limits and defined responsibilities.

2.3 Quality Actuator

The executive closing stage of the quality control loop is the quality actuator. First of all, the quality actuator implements the measures defined by the controller. Additionally the actuator is responsible for providing a primary proof of efficiency. If a solution fails to meet the objectives, the quality actuator has to delegate the responsibility according to defined escalation routines. These routines allow the selection of a different actuator, controller or both. Due to the closed loop character, a continuous monitoring of a measure's long time success is again achieved by the quality sensor.

3 Quality Control Loops in Corporate Environments

Quality Control loops can manifest different characteristics and structures due to their purpose. While some of them have an informal nature – even a coffee break can serve the purpose of a quality control loop - others follow standardized work-flows and descriptions as for example the complaint process.

Quality control loops can be categorized as to their organizational levels they interact with (Fig. 2). Therefore horizontal and vertical control loops are differentiated:

- Horizontal control loops are always located on one organizational level. They describe how a single element of one level is controlled and how the control loops of this level communicate and interact. An example for a control loop on shop floor level can be end-of-line inspections within the production, customer complaint and problem management processes for the order fulfillment or review meeting within product development processes. Processes which are necessary for the management and planning of the business processes such as production or quality planning are attributed to the planning and control level while the strategic level provides control loops for the alignment of the entire production chain.
- Vertical control loops adhere between at least two different levels and describe how the control loops of the lower levels are monitored, controlled and designed – as for example a management assessment of business processes.

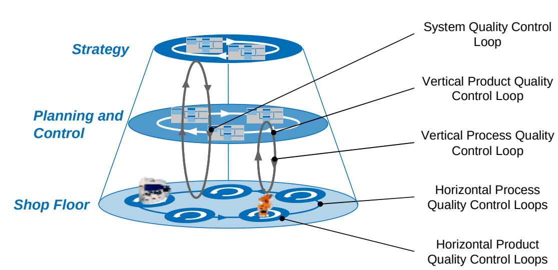

Fig. 2: Horizontal and vertical Quality Control loops on organizational levels

5 Development of a Questionnaire for the Identification of Quality Control Loops and Requirements Specification

The work published here is realized within the research project "Quantifiable Closed Quality Control" – $(QC)^2$. [www.quality-loops.de]. A number of small and medium-sized companies participate in this project. One of their motivations is to formulate their individual expectations in relation to the developed quality control loops described in the previous paragraph. In order to collect these requirements and to formalize the introduced quality control loop description a questionnaire was prepared. It contains three main paragraphs: the first part collects the main working conditions of the company like size, customer portfolio, typical ordering cycles and additional information with regards to the three main aspects of the $(QC)^2$ control loop:

- *Product quality*: Products, product families.
- *Process quality*: Main processes of the company supported with a small reference process model.
- *System quality*: The system quality part collects information mainly about the company's owner/manager expectations structured by the classical viewpoints about financials, market expectations, company organization and main development fields.

The second part of the questionnaire is going to explore the main development fields of the company related to quality management aspects also structured by the three main topics (product, process and system quality). The participating companies can appoint and list here those fields where they require quality control loop developments and select those ones that are described in detail according to the next part.

The third part is a template guiding users to define a quantifiable quality control loop. Firstly the user has to define the output variables for measuring the quality of the field analyzed. The next topic covers the collection and listing of company internal disturbances (they are grouped again as product, process and system related) as well as external disturbances (grouped according to the classical Porter model [6]: competitors and new market entrances, substituting products and new technologies, customers, suppliers, political, social, economical and environmental aspects). In relation to the defined output variables the user has to specify their target values together with the related allowed maximal and expected minimal deviation. Having defined the output qualities the related measuring sensors have to be specified jointly with their measuring frequency and conditions and also the description of the data storage solution. Considering the other side of the control loop the input parameters have to be defined that are used to influence the output quality variables. Specification of the control function connects the output and input parameters with each other. The next group of questions examines the relation between disturbances and control loop elements in order to explore e.g. the stability and controllability of the quality control loop. The final part of the questionnaire analyzes timing features of the loop, such as delays in measuring output values, delays in control feedback or in the changing of the input parameters by the actuator(s) of the loop.

The last part of the questionnaire is related to the software realization of the $(QC)^2$ methodology.

The described questionnaire is used to guide the user in order to define a quantifiable, closed control loop for his/her company. In the next period of the project this questionnaire and the related methodology will be improved.

6 Aggregation of SME's Requirements for Quality Control Loops

In Germany and Hungary almost all the member companies of the $(QC)^2$ project were visited and their general requirements were collected in order to understand the main features of their business model and position, moreover, to have a prioritized list of quality topics where the developed $(QC)^2$ methodology will be applied. During the visits the first two parts of the questionnaire were filled in. There were various similarities and differences identified. Explored similarities were:

- *Company sizes*: the size of all companies is in the same range, the smallest company has around 15 employees however the largest member company has around 300 employees.
- *Customer portfolio*: Companies have various customer portfolios, and all the companies tried to diversify their market representation in order to have less risk

inherited from the individual customers and to be more independent to trends or short time deviation of orders.

- *Typical ordering cycles*: The effect of the financial crisis was the same for the companies from the two countries: the forecast period decreased significantly and also the recent growing of the economy resulted also very high company utilizations. This similarity is natural because the Hungarian market is strongly connected to the German economy.
- *Process quality*: Many similarities were identified in the sales, production, management and support processes: in sales there exist no standard or similar solutions among the companies. Considering production, companies have their own facilities and experienced employees applying these resources significant value-added is generated in the CAD/CAM transition. This is an important field for many improvement activities. Management decisions are very centralized, mainly in the hand of one or sometimes a very small number of people. This applies especially to small-scale enterprises, resulting also that support processes are pushed down into the absolute low and necessary level. Production systems are supported typically with specialized IT tools and production control can be handled as a covered field for most of the firms.
- *System quality*: Many similarities are identified from the system quality point of view. Fully diverse management philosophies were explored; however these are very deterministic for the individual companies' daily operation. In some cases this leads to uncertainty in the company development targets. Financial expectations are fixed for a year and considered monthly for control purposes. Companies mainly set up some plans also for the cost structure, e.g. expected ratios of the different cost types. Financial plans are inherited from two sources: some companies discuss their plans and expectations for the next period (year) with their customers, especially when they have framework contracts besides shareholders' expectations form the other source of requirements for the financial plan. The financial (and other) control is typically realized at two formal levels. One is the comprehensive review incorporating the financials which happens usually at every month or sometimes at quarters. A more detailed but not comprehensive level of control is the typical weekly management meeting with a little bit more expert involvements than the comprehensive review. As in all branches one of the main targets of the companies is to have strong relations with the current customers with increasing business activities.

Explored differences were:

- *Customer portfolio*: The number of customer's branches is higher than in Hungary. The main reason for that is inherited from the activity fields of the companies. In Hungary the companies are active in the same branch they are real competitors having similar customer portfolio, however, the German project members are in different branches covering more broaden customer fields. This difference is also arising in the *product portfolio (product quality)* of the companies.
- *Typical ordering cycles*: The differences in the customer's portfolio resulted differences in the typical ordering cycles, too.
- *Process quality*: The main differences among the companies were that the Hungarian companies are active mainly in cutting tool industry; consequently, they do not have real Research and Development (R&D) processes, the product features are prescribed by the customers. R&D means for them usually cooperation with the customers in order to have a product design that is efficient also from the production aspects, too. This is not the case for the German companies, each of them have their own product development together with the related R&D activities.
- *System quality*: Though many German SMEs have a certificated quality management system according to ISO 9001 series, the SME want to integrate the systematic of quality control loops to their quality management system and even structure their management system according to the design of control loops. In Hungary the situation is different also

among the companies. There are project member companies where more quality management system are operated in parallel however some companies does not certified quality management systems. One of the main differences on the system level arose on the autonomy of employees: the Hungarian companies are going to have high level and precise regulation of the company processes however the German SME point out the importance of the high autonomy of their employees and the necessarily low standardization level within many different processes or tasks. Especially within SME a systematic of quality control loops has to take account to the relatively high autonomy and must not cut down the principles of self-organization and -optimization.

The company visits and their understanding helped to make a prioritized list of fields where the (QC)² control loop methodology is applied. The following field groups were selected:

- Quotation
- Purchasing
- Manufacturing
- Assembly
- Delivery
- Service and application
- Production program planning
- Demand planning
- Process planning and control
- Marketing
- Process development
- Motivation systems

7 The Quality Control Loop Reference Model

A vast majority of producing companies in Europe, especially small and medium enterprises (SME), do not have efficient closed quality control loops, even though they implicitly have a huge amount of interconnected quality sensors, controllers and actuators. As part of the Cornet research project (QC)² "Quantifiable Closed Quality Control" a process reference model for quality control loops has been developed.

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" [7]. Hence reference models are blueprints of best practice, which accelerate the modeling of individual processes by providing a set of potentially relevant processes and structures [8, 9].

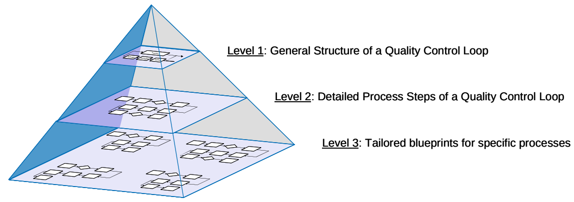

Fig. 3: The (QC)² process reference model

The (QC)² reference model for closed loop quality control comprises three levels of decomposition detail (Fig. 3). The first and most abstract level defines the universal structure of a quality control loop with its three main elements: the sensor, the controller and the actuator. This is also where the main tasks of each control loop element are specified. The second level of the reference model delivers a detailed but generic description of all relevant process steps (activities and decisions) within the scope of closed loop quality control. On this basis companies can identify, describe and optimize the structures of their existing quality control loops and even design completely new ones by means of "design by reuse". Providing a reusable and efficient design with specified sub-processes, the reference model accelerates the modeling process of enterprise-individual quality control loops. The third level of the reference model formalizes tailored blueprints of recommended quality control loops for selected processes of SME's order fulfillment. Each quality control loop of a company can be described and modeled by adapting the reference model to individual needs and constraints.

8 Appointment of the Next To-dos

Based on the afore-mentioned (QC)² process reference model an assessment tool is currently being designed within the frame of the research project. This method will help organizations to assess the closed loop control of individual business processes based on qualitative and quantitative characteristics.

In order to achieve a qualitative assessment of quality control loops a detailed questionnaire will be developed. The questionnaire examines the current degree of accomplishment for each step of the (QC)² reference model with regards to the analyzed process. Hence weaknesses in the structure of a quality control loop as well as in the individual degree of fulfillment of the reference model's process steps can be identified by a company itself even without a profound knowledge of control theory and quality management.

The quantitative evaluation of a quality control loop considers a range of timing parameters such as dead time (delays), costs and resource requirements. With regards to the stability of a closed loop controlled system, dead time is one of the most challenging dynamic elements that occur in most quality control loops. Thus one of the main goals of the quantitative analysis is the identification and reduction of inherent time delays.

Subsequently the process reference model as well as the quality control loop assessment tool will be implemented into a software program. This software will allow a firm-specific adaptation of the generic blueprints as well as the design of completely new quality control loops based on the second level of the (QC)² reference model. Appointed quality control loops can be analyzed directly with the aid of the assessment tool as one module of the software program. Additionally the software will function as an exchange platform for companies that want to share and discuss their own quality control loops or access best practice examples

9 Conclusion

A core element of companies in order to cope with change and disturbances in business processes are feedback mechanisms. The structure and conduct of quality control loops can stabilize the processes by dampening the product and process quality from oscillations caused by disturbances. As characteristic elements of these mechanisms quality control loops serve as the basic model for the identification, simulation, improvement and implementation of feedback structures within companies. The further research will challenge the design of a process reference model and the conception of various blueprint models for quality loops in order to simulate and assess the systems performance.

10 Acknowledgement

The research is supported by the National Office for Research and Technology (NKTH) and EU 7th Framework grant "(QC)2 – Quantifiable Closed Quality Control". The research has also been partially supported by the Hungarian Scientific Research Fund (OTKA) grant "Production Structures as Complex Adaptive Systems" T-73376 and by National Office for Research and Technology (NKTH) grant "Digital, real-time enterprises and networks", OMFB-01638/2009.

References:

[1] Beaujean, P; Schmitt, R., The Quality Backward Chain – The Adaptive Controller Of Entrepreneurial Quality, *Proceedings of DET2009 6th International Conference on Digital Enterprise Technology, Hong Kong, 2009.*

[2] Beer, S.: *The heart of enterprise*. John Wiley & Sons, Chichester, 1979

[3] Schmitt, R.; Pfeifer, T., *Qualitätsmanagement*, Hanser Verlag, 2010

[4] Schmitt, R.; Pfeifer, T.; Stiller, S.; Beaujean, P., Introducing quality control loops for the integrated analysis and design of stable production systems, *10th International Symposium on Measurement and Quality Control, 2010*

[5] DIN 19226 *Leittechnik; Regelungstechnik und Steuerungstechnik*

[6] Porter, M., *Competitive Strategy: Techniques for Analyzing Industries and Competitors*, Simon and Schuster, 1998

[7] Rosemann, M.; van der Aalst, W.M.P., A Configurable Reference Modelling Language, *Information Systems, (32), 2007*

[8] Rosemann, M., Application Reference Models and Building Blocks for Management and Control, *Handbook on enterprise architecture,* Springer Verlag, 2003

[9] Matook, S.; Indulska, M., *Improving the quality of process reference models: A quality function deployment-based approach,* Decision Support Systems, (47), 2009