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Design and assessment of quality control loops for stable business processes

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Abstract: Due to their open and dynamic character, business processes in lack of adequate feedback mechanisms tend to become unstable in case of unanticipated disturbances or target adjustments. In order to face this challenge and to ensure entrepreneurial quality the implementation of quality control loops is proposed, whose design is derived from cybernetics. The paper discusses requirements for the characteristics of quality control loops and presents a new approach for their assessment implemented in software. The developed tool also serves as a knowledge exchange platform since it provides an opportunity for exchanging standardized control loop elements.

Keywords: Quality, Quality Control, Performance

1. Introduction

In light of intense international competition companies must excel in order to prevail. At the same time, they are obliged to decrease production and labor costs while increasing both product quality and productivity. An aggravating factor is the dynamic, crisis-shaken environment in which companies are operating today. Hence they are currently dealing with barely predictable and constantly changing conditions from the planning level down to the shop floor [1,2].

To survive in today's volatile market companies need to improve the robustness of their processes vis-à-vis internal and external disturbances [3,4]. Uncontrolled business processes in lack of adequate feedback mechanisms tend to instability in case of unanticipated disturbances or target adjustments. Furthermore, the dynamic behavior of business processes is scarcely known to companies and it often varies over time, due to personal and organizational changes. The depicted problems are well-known in cybernetics. In order to cope with disturbances in technical systems, closed control loops are implemented. However, control technology proves that wrong or less precisely designed control loops tend to amplify a system's oscillation caused by disturbances and may even result in its collapse. Control theory differentiates between feed-forward and feedback control. Only the second one allows for an adequate compensation of disturbance and sufficient robustness within the controlled system. To cope with the above-mentioned challenges the implementation of closed quality control loops is proposed for business processes [5-7].

As examples such as the Deming–cycle (plan-do-check-act), Six Sigma's DMAIC-cycle (define-measure-analyze-improve-control) and ISO 9001 show, feedback mechanisms are well-known in the field of quality management. Nonetheless, the structured design of quality control loops in companies is still a problem. The above-mentioned circumstances require a new cybernetic approach for the design and assessment of reactive processes in quality management [8-10].

2. Cybernetic Approaches

The theory of cybernetics originates from the theoretical – that is, logical, conceptual and mathematical – analysis of self-regulation, autonomy, hierarchy of organizations and functioning in organisms [11]. First Wiener published findings from the application of cybernetics in order to depict complex relations within systems [12]. Early cybernetics, however, did not differentiate between technical (machines) and socio-technical systems (organizations). This, as one of the main points of criticism, led to a new thinking considering the human being as an inherent part of a control system [13]. Subsequently, cybernetic thinking was applied in various branches of science. Today's vast variety of definitions and conceptions for cybernetics reflects this broad application; see [12,14-18]. Kaufmann differentiates between three main branches of cybernetics which have evolved since 1965 – the scientific and technological branch, the humanistic and physiological branch as well as the branch of economic and social sciences – with quality management being a sub-branch of the latter [19]. According to Glaserfeld, cybernetics is 'metadisciplinary, which is different from interdisciplinary, in that it distils and clarifies notions and conceptual patterns that open new pathways of understanding in a great many areas of experience.' [11] Hence, cybernetics provides a language for describing and understanding the dynamic behavior of complex systems. Based on this understanding, cybernetics can be used as a foundation to develop solutions to both technical and organizational challenges.

3. Towards Controlled Entrepreneurial Quality

International standard EN ISO 9000:2005 defines quality as the 'degree to which a set of inherent characteristics fulfills requirements' [20]. This basic definition of quality is based upon the degree of the overlap between market requirements and product features. Aside from customer needs, legislative and normative requirements must be taken into account as well. The normative definition of quality expressly includes these in the term 'requirements'. However, this understanding of quality, which is basically a reduction to an alignment of actual and nominal conditions, is insufficient for entrepreneurial practice. In today's dynamic environment, this one-dimensional understanding proves to be insufficient to prevail against competitors [21,22]. Even companies which offer products of high quality are, nevertheless, driven out of the market. Of great importance in this context are the associated costs [23]. Excessive expenditures render sustainable entrepreneurial success unachievable.

3.1. Entrepreneurial Quality Management

In order to rise to this challenge, the classical understanding of quality has to be extended by an additional dimension. Following an entrepreneurial understanding, a company's performance is comprised of two main components: the sum of all actions determining a company's orientation and direction on the one hand and all available skills and organizational structures of the company, on the other. Consequently, high entrepreneurial quality can only be achieved when customer requirements are squared with corporate skills and corporate orientation. This implicitly leads to a new understanding of quality as the immediate and waste-free fulfillment of market requirements while taking strategic objectives, entrepreneurial conditions and available resources into account. Entrepreneurial practice, thus, necessitates the application of an organizational framework, which allows for an appropriate active influence on company performance.

The Aachen Quality Management Model (Fig. 1) provides such a frame of action for all quality related entrepreneurial tasks and processes, while not being restricted by the traditional definition of quality.

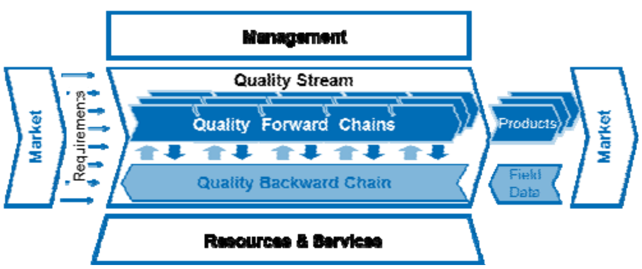

Fig. 1. The Aachen Quality Management Model [6].

As the model's core element, the Quality Stream, receives market requirements and lifecycle data as input factors and evaluates these. At the same time, the Quality Stream represents the customers' voice and assumes their perspective since the processes contained therein must generate the overlap between customer requirements and company performance. In industrial practice this overlap is generally never complete, due to the existence of influencing factors such as superordinate company principles, company capabilities and economic aspects.

On the one hand, the determination of a company's orientation requires action from the management perspective, which must align the strategic company orientation with the company's abilities. The primary goal is the optimization of operations. It also ensures the coordination of the various business processes so as to take advantage of synergies and preserve resources.

On the other hand, the company perspective focuses on the goals designated by management and the optimization of required processes. This is contingent upon the optimal allocation of internal company resources. Over time this allocation must be evaluated continuously and adapted in accordance with the company's continuous improvement process.

3.2. The Quality Backward Chain – A Framework for Reactive Quality Management

Within the Quality Stream of the Aachen Quality Management Model, multiple Forward Chains represent all activities for the development and engineering of various product groups and product generations. As opposed to this, the Quality Backward Chain provides a generic feedback structure for the derivation of reactive and corrective measures to improve product and process quality (Fig. 1). In order to connect the Quality Backward Chain to different elements of the Quality Forward Chains as well as to implement closed loop feedback mechanisms, quality control loops are introduced as an approach to the control of entrepreneurial quality.

The global structure of quality control loops is derived from the German standard for control technology DIN 19226 [24]. However, the diversity of business processes and the impossibility to accurately model and predict the behavior of socio-technical systems requires the application of cybernetics in a much broader sense. The consideration of reactive processes in quality management as closed loops allows for the quick identification of weaknesses and potential threats to the stability of individual processes, respectively, the production system as a whole. Following the technical definition of a control loop, a quality control loop can be characterized by its three main elements – the sensor, controller and actuator [25].

The **sensor** monitors the state of the controlled system and informs the controller about significant deviations from a desired system status. It is distinctive for a quality control loop, that sensors are usually not capable of monitoring the quality of a product or process continuously. Typical quality sensors are reports from employees, failure detections during quality inspection as well as customer complaints or key figure reports.

In case of a detected problem, an appropriate **controller** is selected, which is responsible for the selection of measures in order to make adjustments to the controlled system. Based on a thorough analysis of the reported problem, corrective actions and, where necessary, containment actions are defined by the quality controller.

Based on selected solutions, a quality **actuator** is assigned to the problem. Its main task is the implementation of measures within the controlled process and, thus, the closure of the quality control loop itself. Additionally, the actuator is responsible for providing a primary proof of effectiveness by immediately evaluating the success of a measure. A long-term evaluation of measures is – due to the closed loop character – constantly provided by the quality sensor [26].

4. A Reference Model for Quality Control Loops

The concept of closed loop quality control is suited for all kinds of business processes. For each application the individual tasks of the three control loop elements need to be adapted to the specific situation and should be documented in order to allow for a transparent process. For a practical adaptation of this generic concept, a reference model for quality control loops has been developed within the CORNET project $(QC)^2$ - Quantifiable Closed Quality Control.

The main objective of a reference model is 'to streamline the design of enterprise-individual (particular) models by providing a generic solution' [27]. Consequently, reference models are considered as blueprints of best practice, which accelerate the modeling of individual processes by providing a set of potentially relevant processes and structures.

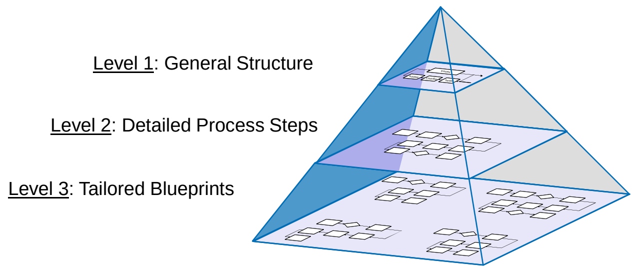

Fig. 2. Architecture of the (QC)² reference model.

The presented reference model for closed loop quality control is hierarchically structured on three levels (Fig. 2). Within the first and most abstract level of the reference model, main process phases are defined and allocated to the three elements of a quality control loop. The second level of the reference model delivers a cross-functional flowchart which specifies all relevant process steps of a quality control loop (activities, decisions and information flows) whereby three swimlanes represent the sensor, controller and the actuator (Fig. 3). Furthermore, a generic but detailed description of each step is provided in order to convey its importance within the process. Each task is further divided into smaller sub-tasks until an elementary level is reached. The third level of the reference model serves as a knowledge-database as it provides tailored blueprints of quality control loops which were published by participating companies.

Various industrial applications prove that companies are able to identify, describe and optimize the structure of existing quality control loops, based on this generic reference model. Companies are even able to design completely new processes by means of design by reuse. The (QC)² reference model significantly accelerates the modeling process of enterprise-individual quality control loops by providing a reusable and efficient design with generic sub-processes. Each quality control loop of a company can be described and modeled by adapting the reference model to individual needs and constraints.

Furthermore, the reference model provides the basis for the (QC)² Loop Manager software with its integrated quality control loop assessment tool (see Section 6).

5. An Approach to the Assessment of Quality Control Loops

Based on the introduced (QC)² reference model and under consideration of cybernetic requirements, quality control loops can be assessed. With this ambition a new approach has been developed and implemented in software.

The primary part of the assessment tool applies a capability maturity model for entrepreneurial quality control loops. For each step of the reference model, base practices are appointed. Base practices are essential activities leading to the defined target of a process [28]. For the assessment of a quality control loop, an internal or external assessor collects data on the process by various means e.g., interviews with employees or sifting documents. Based on the findings, the characteristics of the analyzed loop are then compared with the aforementioned predefined base practices. Thereby, the fulfillment of each criterion is rated on a scale from one (not fulfilled) to five (completely fulfilled). The assessment model provides an aggregated evaluation of the process maturity level on different levels of detail (process steps, phases, control loop elements). Additionally, strengths and weaknesses of the process are correlated with different characteristics of the quality control loop, e.g. documentation, process transparency or the ability to monitor process performance. The realization of an assessment easily reveals structural and operative weaknesses within the reactive processes of a company which, otherwise, implicate poor performance of the quality control loop and may result in instable business processes.

Simultaneously, exploration questions aim at collecting detailed information on the adaptation of the generic reference model to company-individual and process-oriented constraints. Based on the acquired information, a description of the sensor, controller and actuator is extracted, which serves as documentation and enables companies to trace back adaptations to their processes. A standardized format allows for the exchange of control loop descriptions even across company boundaries.

Due to the inherent characteristics of socio-technical systems, typically, all elements of a quality control loop are characterized by inherent time delays. The time delays may result from communication lags, processing times as well as limited availability of employees within the quality control loop.

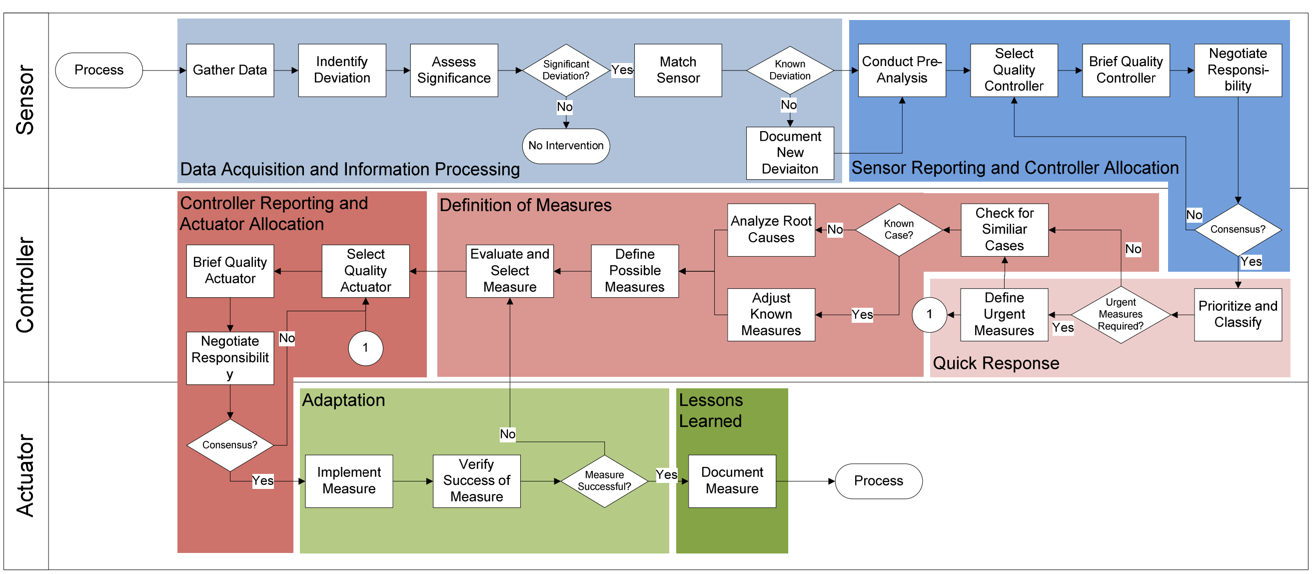

Fig. 3. Second level of the (QC)² reference model.

Hence, a main target of the (QC)^2 assessment tool is, besides the analysis of structural weaknesses, the identification of inefficiencies and time delays. Time delays within quality control loops can partially be eliminated e.g. by the improved coordination of a sensor's frequency with meetings and steering board schedules. Therefore, different distinctive timing parameters of the control loop are determined and analyzed.

6. The (QC)^2 Loop Manager

To enable companies to deploy the novel concept of closed quality control loops, an information technology solution is introduced. Besides the aforementioned aspects of the introduced cybernetic approach to quality management – the reference model and the assessment tool – the developed (QC)^2 Loop Manager software was extended with further collaboration and information exchange functions. Therefore, the presented approach was analyzed from two perspectives. One is the efficient realization and usage possibility. The other one considers the expectations of the targeted user group working with complex production systems.

The concept of the software combines the assessment of a quality control loop with its documentation and step-by-step improvement. The tool can additionally be used to efficiently guide the user through all the steps which are required for defining a new quality control loop. Consequently, the primary procedure is the evaluation of the process. Documentation of the control loop characteristics is incorporated into the different stages of this analysis.

Initially, the controlled system has to be defined. For this purpose, the associated business process of the control loop has to be appointed. Processes can be selected from a previously defined, hierarchical process list consisting of the main processes of a typical manufacturing company. This specification will help later on to exchange and benchmark control loop definitions, using the community based collaboration platform.

The graphical representation of the (QC)^2 reference model and the interactive selection highlight process steps and form an intuitive graphical user interface which guides through the entire assessment, helping the user to close the quality control loop (Fig, 4-a). The software hence leads the user through consecutive lists of questions which are related to individual tasks in the quality control loop. Each list consists of two kinds of information objects (Fig, 4-b). Specific, task-related assessment questions with a rating scale of five form the first question type. The second type determines and stores names, parameters and descriptions of the attributes of the selected quality control loop task. The questions relate to the elements and process steps of the generic reference model and are thus applicable to all kinds of quality control loops. However, the answers to the exploration questions specify the considered process and the applied control solution.

Based on the answers to the rating questions, the maturity level of the whole quality control loop, its elements and process steps is calculated and the software delivers immediate feedback to the expert (Fig. 4-c). Thus, this feature highlights the impact of individual, specific answers upon the aggregate rating of the whole quality control loop, its main elements and process steps.

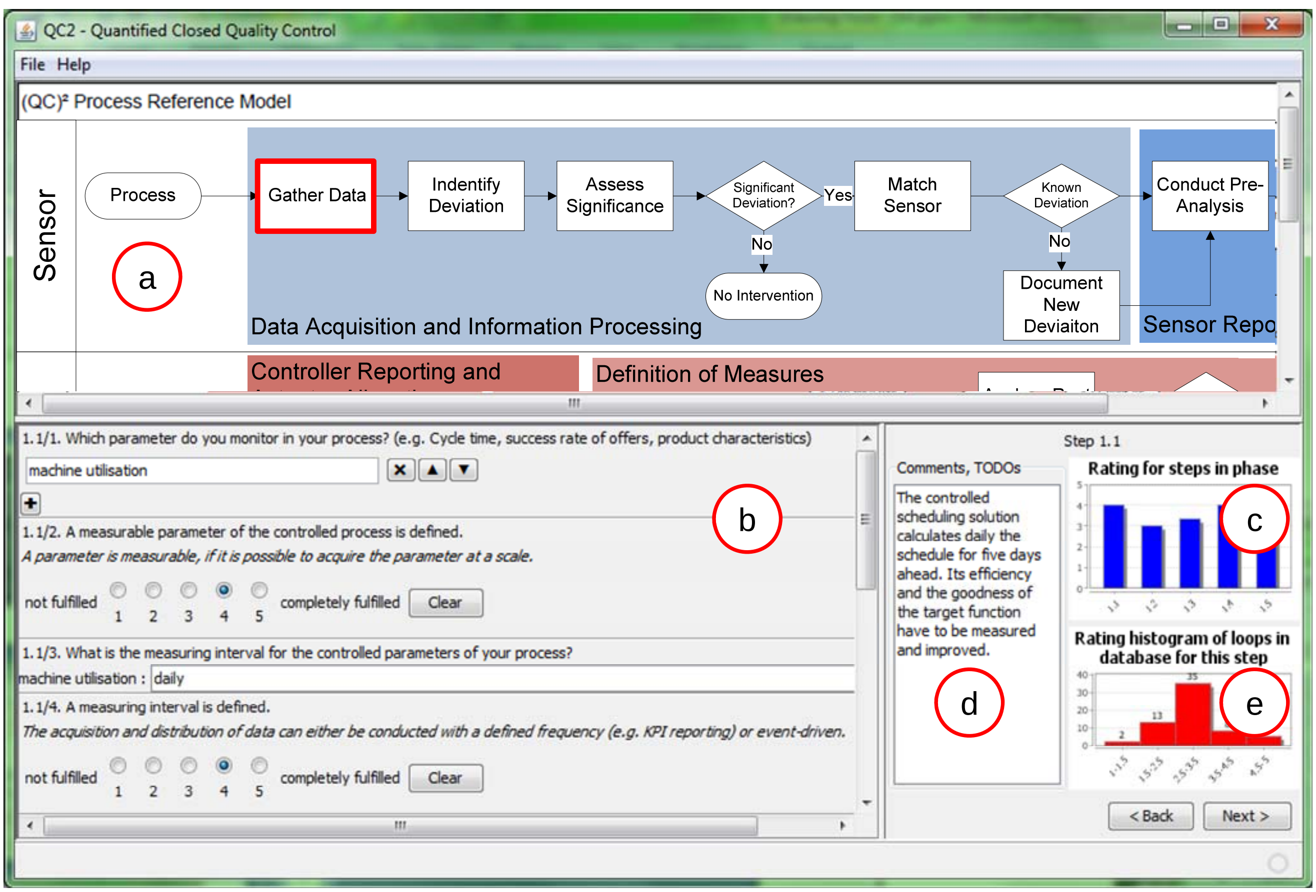

Fig. 4. The (QC)^2 Loop Manager guides the user through the evaluation and documentation of quality control loops.

Moreover, having assessed and defined all elements of the quality control loop, the solution supplies an overview with clear appointments of existing weak points and appropriate guidance. Consequently, the user can identify the places where a quality control loop has to be revised and improved. After the application of appropriate changes or adaptations, the improvement effect can be calculated. This feature makes the control loop quantifiable and enables the continuous improvement of existing quality control loops.

Beyond the parallel evaluation and definition of company individual quality control loops, the introduced system is extended with a central information sharing mechanism. To encourage the cooperation among the quality control loop experts, a central service is available to evaluate loops or loop elements in comparison to the control solution defined by other companies and experts. When defining or assessing a quality control loop of a preselected, standardized process, the software searches – when it is allowed by the user – for other control loop definitions available in the central database. Ratings of centrally available control loop elements for the same process are then highlighted. When defining e.g., the sensor for measuring the efficiency of the short-term production scheduling process, the software shows promptly that there are e.g., four production scheduling control loop sensors in the central database with a rating of e.g. 3.67 in average, while the best sensor has a rating of four (Fig. 4-e). This service indicates that it is possible to view and download good practice examples from the central database. Information sharing is possible in the opposite way, too. Having defined a complete loop or a loop element, the expert is proposed to upload a good solution as an example to the central database in order to help others with suggestions and possibilities. That way the central service is a continuously growing set of good and best practice quality control loops and elements. This will encourage the emergence of a live community for quality control loop experts in manufacturing companies.

The analysis of various information sharing methodologies suggests an information sharing for the $(QC)^2$ solution which is regulated by means of reward points. Upon registration, a user will receive a certain amount of reward points. On the one hand, when downloading available loops or loop elements, the points are decreased. On the other hand, when uploading good results, the points are increased. By this means, participants are motivated to exchange information among each-other in order to continuously improve the solutions available for the whole community. The central database of the highlighted service will initially provide many good examples from different processes of various participating companies. Should a company or an expert not intend to participate in this knowledge exchange, the software tool can also be used as a simple stand-alone solution.

7. Industrial applications

Two industrial cases represent the benefits that can be achieved by the application of the presented cybernetic approach and the developed software solution. Both applications were performed at small and medium-sized production companies.

The first application of the presented approach was accomplished at a Hungarian company producing and designing machine elements, tools, fixtures and special machinery. The management was not satisfied with the marketing process of the company, however, they were not able to precisely state their expectations and required activities for the improvement of daily business. The $(QC)^2$ solution was applied in order to streamline the improvement process. After the first assessment of the previously unstructured quality control loop, the analysis continued with the exploration of disturbances in order to identify sources of typical problems. A lack of customer approval, highlighting them as strategic partners, changes in the allowed marketing budget during the year, deviation requests during the manufacturing of products as well as supplier related quality problems are some examples. Parameters and expected target values for monitoring the process performance were specified next. The number of contracts and orders are among the indicators for describing the results of the marketing process, together with e.g., the amount of requested and prepared proposals, the amount of new customer contacts and company visits within the analyzed period. After defining the corresponding target values and related tolerances, possible controllers for the marketing process were highlighted in conjunction with possible delays for eliminating any root causes of unsuccessful marketing activities. Marketing budget adjustments require e.g., a quarter of a year, whereas improvements of appropriate language skills take about one year for the company. Among other things, project managers, purchase personnel, professional marketing consultants and the general manager are actuators that can introduce stabilizing measures to the marketing process. Potential measures were the adaptation of contact lists, the improvement of available marketing materials as well as the limitation of accepted deviation requests. With help of the introduced $(QC)^2$ reference model, the marketing quality control loop was defined and is operating efficiently and effectively regularly for six months now.

After having run the improved quality control loop for a year, its achievements were evaluated and a next level of improvement was initiated using the $(QC)^2$ Loop Manager. The feedback mirrored extremely good results: almost all planned improvement activities were introduced and implemented in daily business. Target values for the marketing process were defined and relevant process outputs are now gathered and monitored in a structured way. Moreover, all significant deviations are analyzed regularly and corrective actions are introduced where necessary. Examples of successful measures which were initiated by the quality controller are enhancements to marketing employees' language skills, the introduction of new marketing materials, as well as a software-assisted process for tracking customer contacts and visits.

According to statements of the company's management, the deliberate control of marketing activities is a major benefit of the novel, software supported, $(QC)^2$ approach. The depicted activities enabled the company to successfully manage and improve its marketing process. Moreover, this development substantially contributed to a boost in market share: the company increased its number of proposals by around 15% (effectivity improvement) and the customer order ratio by even 50% (efficiency improvement). The average duration of cooperation contracts almost quadruplicated and, moreover, the number of customer's markets (international customers) doubled within one year. These positive effects significantly improved the company's strategic position and contributed to a nearly doubled company income. Nonetheless, last year's developments also resulted in new disturbances to the marketing process, such as full utilization of available marketing and production capacities as well as shortage of skilled labor.

Additionally, the $(QC)^2$ Loop Manager software has successfully been applied by a leading German manufacturer of industrial control valves and actuators. A quality control loop for the final assembly of gas valves has been improved by applying the presented approach. Prior to the first assessment of the process, around 27% of all gas valves required re-work within the assembly process in order to meet customer requirements for a final leak test. Assisted by the presented software solution, an interdisciplinary team first documented and assessed the currently installed quality control loop. At the same time, appropriate measures for the improvement of the quality control loop, which came up during discussions, were gathered immediately within the designated text field of the software (Fig. 4-d). The assessment revealed a major weakness within the definition of corrective actions. Whereas urgent measures were usually launched by the controller in case of significant deviations, the root causes of the problem were seldom identified and never eliminated. Based on these findings, the quality controller was redesigned according to the $(QC)^2$ reference model. The existing controller was extended by a defined process for the analysis of root causes and for the definition of corrective measures. For that purpose a team of assembly, engineering and sales experts was established which meets biweekly in order to analyze significant deviations and to define measures which are then implemented according to the priority of the problem. All assembly issues are now being thoroughly analyzed and partially result in improvement and redesign projects in order to provide corrective measures aiming at the root causes of each problem.

With the improved quality control loop operating for six months, the company was able to increase the First Time Yield (percentage of good parts that make it through the entire assembly process without any failures) of its final assembly process from 73% to nearly 85%, aiming at 95% in the close future. According to statements of the responsible persons, the benefits to the company clearly outweigh all related investments made. The significant improvement of this important metric clearly shows the benefits and achievements of well-designed quality control loops in industrial applications.

8. Conclusion

The paper discussed a cybernetic approach to reactive quality management. Facing internal and external disturbances, companies can stabilize and even increase the performance of their business processes by implementing closed and quantifiable quality control loops. Though the advantages of feedback mechanisms are renowned in quality management, nonetheless, the design of quality control loops is ordinarily not optimized in practice.

The paper presented a new approach to the structured design and assessment of quality control loops. Within the research project $(QC)^2$ a reference model-based assessment tool has been developed. This tool is embedded in a software solution which additionally provides the opportunity to document, manage and share quality control loops even across organizational boarders.

The advantages of the developed methodology and the implemented software were highlighted from the point of view of small and medium-sized enterprises. The adaptation of the quality control loop reference model to the specific constraints of marketing was highlighted. From several ongoing pilot applications, an example for the software-assisted assessment and documentation of a manufacturing quality control loop was presented in detail.

The paper has shown that the structured design and analysis of quality control loops, supported by an appropriate software solution, can bring numerous immediate and long-term benefits for companies operating in highly dynamic markets while dealing with various internal and external disturbances to the quality of products and processes.

The $(QC)^2$ Loop Manager and the extended information sharing services will be released online upon official completion of the research project [http://qc2.sztaki.hu/].

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