Cross-Process Production Control by Camera-Based Quality Management Inside a Logistic Assistance System

Markus Zajac and Christian Schwede

Abstract A holistic integration of quality measurement into process control has a huge potential especially for SMEs in the areas of production and logistics. Since poor results of quality measurements can influence the whole order-to-delivery process the quality data should be included as soon as possible in the decision process as part of a superior order control. This paper presents results of the Supply Chain Execution project that developed a low-cost camera-based quality measurement system and integrated it into a Logistic Assistant System that allows for simulation-based process control considering data from the whole supply chain. This lean low-cost approach, which does not depend on sophisticated IT-infrastructures and management systems, yields results that are especially interesting for SMEs.

Keywords Quality management · Production control · Logistic assistance system · Camera-based computer-aided quality assurance

1 Importance of Quality in Production Processes

Globalization and active market dynamics have noticeable impacts especially on small and medium-sized enterprises (SMEs). SMEs form the majority of companies in Europe and thus play a central role in contributing to the overall economic success (Winham 2012). The impacts emerge essentially from shorter product life cycles, the demands for cost-effective products, from a high product variety and increasing competitive pressure. Besides implementing optimal production processes, SMEs have to fulfill associated requirements related to ergonomics and safety at work (Bornewasser and Zülch 2013)—last but not least to comply with

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current norms and laws. A quality management system to ensure the quality of work and product is indispensable. As small companies often develop specialized and customized solutions, the quality of offered products and services determines their competitive position (Mohanty 2008).

A non-existent or insufficient quality management system may lead to various problems and consequently to additional internal and external costs (Dobb 2004). Costs at the production location (internal costs) originate for example as a result of defective goods, rework or product downgrading (Oakland 2014). External costs are customer related and originate for example in returns and recalls, liability claims and special transports (Dobb 2004; Oakland 2014). Hence, a consequent quality management system supports enterprises to fulfill the required product quality as well as legal requirements regarding production processes. The approach presented in this contribution also supports in particular ecological aspects of the supply chain like reducing the number of defective goods, superfluous transports and packaging material. For the establishment of a quality management system in enterprises, IT support is indispensable.

The structure of this contribution is as follows. Section 2 discusses general aspects of quality management systems and computer aided quality assurance. In Sect. 3, we elaborate on Logistic Assistance Systems (LAS) and the utilization of quality management inside LAS. Section 4 describes a developed Logistic Assistance System for production control as part of a project supported by the German Federal Ministry of Education and Research (BMBF). We end with conclusions in Sect. 5.

2 Quality Management and Computer-Aided Quality Assurance

The core task of quality management (QM) consists of the implementation of quality elements or aspects (Benes and Groh 2012). These elements include quality planning, quality control, quality assurance and quality improvement (Brüggemann and Bremer 2012). Table 1 provides a short overview of quality elements.

Since quality control is based on monitored process results and thus plays an essential role in the context of cross-process production control, it will be the focus of this paper. The so-called immediate quality control intervenes in the ongoing production and assembly processes (Benes and Groh 2012). The term production control is closely related to quality control. Production control is integrated in the quality assurance process and can be organized in control loops of varying scope (Rosenberger et al. 2010). Small control loops are used for controlling individual production processes in which current values are compared with nominal values. In case of deviations beyond the tolerance limits, corrective actions can be performed instantaneously. To achieve a cross-process production control (e.g. in a multi-stage production system), quality control has to be applied in all corresponding

Table 1 Quality elements

Quality element	Function
Quality planning	Within quality planning, the quality goals, necessary execution processes as well as corresponding resources are specified
Quality control	Primary tasks are monitoring and if necessary correction of an item to comply with quality requirements. Here the results of quality tests are compared with the goals of the quality planning. In case of deviations, corrective actions are performed
Quality assurance	Quality assurance focuses on providing confidence that quality requirements are fulfilled. Quality planning and quality control are subtasks of quality assurance
Quality improvement	Summarizes all measures to increase effectiveness and efficiency in processes and activities dealing with quality aspects

production processes or activities. In this context, statistical process control (see below) is one method to make the production processes stable by integrating it into an overall quality improvement program of the enterprises (Montgomery 2008).

In case of observed deviations based on a target/actual comparison, appropriate measures have to be taken to ensure immediate corrections by a responsible employee (Benes and Groh 2012). In order to gather actual values, the quality control procedures make use of machine-supported control circuits. Here, samples of the production process are regularly gathered and the measured values evaluated. There are two types of process control (Benes and Groh 2012):

- Statistical process control (SPC): In the course of the production process, samples are taken at certain times. This process control intervenes at an early stage in the production process to counteract negative trends by applying appropriate corrective actions.
- Continuous process control (CPC): With this technique, a 100 % check takes place, resulting in a direct feedback and hence continuous machine control. This type of process control is used, when even the smallest analysis intervals are inappropriate, for example during particle measurement (Dietrich and Wilczek 2002).

To provide automatic acquisition of current quality data within the scope of SPC or CPC for quality tests, Computer-Aided Quality Assurance (CAQ) as part of quality control is applied. CAQ is an IT system for storing and preparing quality relevant data (Benes and Groh 2012). Another important function of CAQ systems consists of test planning as well as providing quality planning and quality test data. Quality data collected along the supply chains can be distinguished in different categories like quality data of suppliers, material testing for incoming goods and quality measurement in production (Brüggemann and Bremer 2012). In production processes, quality relevant machine-data, like rotation, pressure or temperature data can be collected by means of sensors and metrics (Ansari-Ch. et al. 2011). SPC however may become increasingly complex, because of the huge number of sensors and data sources. In such cases, multivariate statistical process control (MSPC) may provide a solution. In MSPC, variables are aggregated in order to master the increasing complexity, as exemplified in the wood pellet industry (Lestander et al. 2012).

Besides collecting machine-data, digital image capturing by camera systems as well as digital image processing are already in use. Camera based systems are replacing the manual control by experts step by step. Megahed and Camelio (2012) show the feasibility of fault detection in a manufacturing environment by using image recognition techniques. Dobrzanski et al. (2007) demonstrate the identification and classification of possible defects occurring in castings of automotive Al–Si–Cu components. In the timber industry, image processing applications for checking the wood quality are widely used (Molder and Martens 2011). To predict the breaking strength of pinewood boards, a real-time camera-based system in conjunction with digital image processing for calculating local grain direction was evaluated positively (Hietaniemi et al. 2014).

3 Quality Management Within Logistic Assistance Systems

To ensure quality requirements within production processes, quality control tasks are performed periodically. In particular, target values of processes are compared against measured actual values (cf. Sect. 2). In case of deviations of actual values from target values, it is necessary to select an appropriate action to ensure immediate correction. Depending on the size of the deviation, a range of possible measures to be selected is available. The selection of production control measures may be quite difficult because of both additional information as well as an impact analysis of the chosen measure, such as adherence to schedules, is needed. For instance, one measure may consist in swapping a material of a current job with a material of another job to complete a customer order in time. For this purpose inventories and scheduled orders have to be taken into account when making the decision. It is therefore necessary, to support the human operator in the choice of a measure by using appropriate IT tools.

To support human planers in decision-making, so-called Logistic Assistance Systems (LAS) have been deployed. These IT systems offer functions such as information processing, information transparency and decision support (Bockholt et al. 2011). LAS integrate all process-relevant data into a logistic process model (transparency) and present this data to decision makers and experts (single-point-of-truth). This data may include inventory levels, customer orders as well as transportation data from the Supply Chain and production programs. As part of information processing, data validation and threshold calculations on integrated data can be performed and subsequently presented. Another major functionality is the support of the human decision process (Kuhn et al. 2008). To this end, effects of decision variants are pre-calculated by using discrete event simulation. Based on the results of the different scenarios the human user can then take the best decision for the current situation. This method combines experience of human decision makers in the selection of basic scenarios with powerful evaluation methods of these scenarios in complex environments. LAS already found their way into the industry in various application fields (Deiseroth et al. 2013; Hegmanns et al. 2014; Müller-Ohe et al. 2014). For example, within collaborative planning in the automotive industry, a LAS is being used to control engine parts and assembled engines in the supply chain (Bockholt et al. 2011).

In contrast to LAS, CAQ-systems are software-based realizations of QM (Brüggemann and Bremer 2012) and provide support in process documentation, in process-integrated quality management, in data-monitoring and in the logging of test results. Thus the focus of CAQ-systems is on carrying out measured value collection as well as data transfer and storage. Yet the required decision support based upon scenario- and process-based measures evaluation is not offered. Hence, a promising approach is the combination of LAS with CAQ systems to support decision makers by offering assessed available options based on collected quality data by a CAQ-system. Since quality data is gathered along the supply chain in large volumes (cf. Sect. 2) and may have an influence on the entire order to delivery process, it is necessary to prepare that data for use in decision making (Brüggemann and Bremer 2012) in LAS. In terms of transparency, quality data have to be transferred into a logistic model first and subsequently included in decision making procedures. For the transfer into a logistic model, LAS can either integrate modules of CAQ systems or communicate with these systems through service interfaces to obtain gathered quality data or the results of material testing. Once the data is transferred, it can be processed to provide scenario-based options to the decision maker. Because quality data is linked to different locations, it can be used to control the material flow in various processes in the supply chain.

4 Supply Chain Execution Project

This contribution describes the results of the research project Supply Chain Execution (SCE). Within this project, that was supported by the German Federal Ministry of Education and Research (BMBF) and is a part of the EffizienzCluster LogistikRuhr research cluster, prototypes of LAS for wood quality measurement based cross-process control have been developed for SME application partners within the furniture industry. After measuring poor quality of certain planks in this industry, a couple of actions are possible depending on the results of the measurement. The focus of the LAS is in supporting the human planner in the selection of an appropriate production control measure.

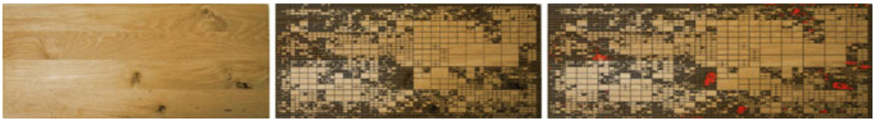

Fig. 1 Image processing in the three steps: unprocessed, segmented and recognized

4.1 Methodical Approach

To enable a cross-process production control, so-called control points are identified by analyzing the supply chains of the furniture manufacturers. At these control points quality control takes place and in case of deviation, appropriate measures are to be taken. The identified control points have the biggest influence on the production control and are typically anchored to production as well as assembly processes (Yüzgülec et al. 2013).

To perform quality measurements to obtain the quality test data at identified control points a camera based CAQ system was developed. In timber production, edge-glued planks have to be tested in various processes of the supply chain. In accordance to SPC (cf. Sect. 2), quality data is collected at pre-determined intervals. To obtain the quality score, a plank is recorded by a camera first. Subsequently, the quality score is calculated by a digital image processing algorithm. Figure 1 shows the three steps of the algorithm.

The first step is to acquire the recorded plank image. By using of grayscale calculation, the image is divided into segments by comparing the surrounding area in the second step. In the third step, the algorithm examines the image on knotholes and calculates the quality score value. In doing so, this CAQ system is able to capture two types of information:

- The quality score of a plank: This score is determined algorithmically, as described above.
- The unique ID of a plank: Besides the quality score, a unique identification number of the plank is also delivered by the system. Therefore, RFID transponders have been integrated in the production of edge-glued planks in order to allow tracing during the entire manufacturing process.

Relative to MSPC (cf. Sect. 2), all captured variables are combined to one unit (cf. the concept of Premium Service in Sect. 4.2). Finally, the gathered information must be further processed to validate the quality score and to provide decision support, if necessary. For this purpose, information is provided to the LAS.

4.2 Logistic Assistance System

The basis of the developed LAS is constituted by logistic service components (further called services), which enable a flexible and customer specific configuration

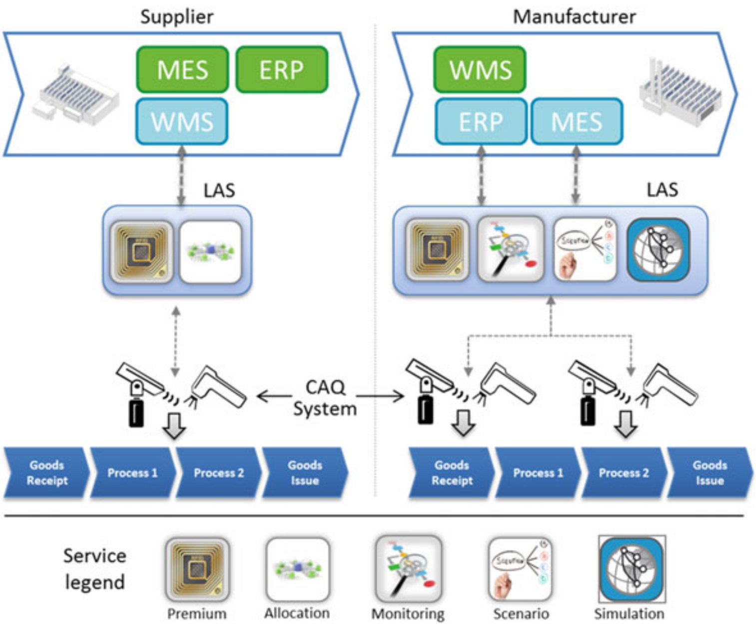

Fig. 2 Schematic figure of LAS integration

of Logistic Assistance Systems. The LAS is integrated in supply chain processes of the furniture manufacturer and imports data from both the CAQ system and various back-end systems (cf. Fig. 2). Subsequently the data are processed by the services of LAS. Besides quality data, back-end systems are requested to receive orders and allocated items (planks). As planks are equipped with an RFID transponder, they will be unambiguously assigned to an order within the order planning. The orders include additionally information about their plank target quality scores, since furniture manufacturers are producing for various customers with different quality needs. Hence, it is possible to use a plank for manufacturing a cupboard door as well as for the rear wall of a cupboard (Yüzgülec et al. 2013).

Table 2 briefly describes selected services which have been customized for the SCE project.

The following section describes the service workflow with the aim to provide production control measures in case of poor quality of a plank. The pressing of planes is one process at a furniture manufacturer which was exemplarily selected as a control point for the demonstrator. At the beginning, quality scores are regularly compared by the Monitoring Service (by requesting the quality data as well as a plank ID from the Premium Service). The goals of the Monitoring Service are compliant to the quality control tasks as described in Sect. 2. For each test, the target quality score is resolved first. For this purpose, the Monitoring Service communicates with back-end systems to resolve the order (and the deposited target quality score) by sending the plank ID. The result of the test is displayed to the

Table 2 Selected services of the LAS in SCE project

Service	Function
Premium service	These services are used to encapsulate data from multiple sources. In the SCE project, one unit describes data of one plank. It consists of captured quality scores and the unique identifier of the plank
Monitoring service	This service performs close to real-time IT monitoring of the quality information from Premium Services. The received quality information is enriched with a predefined quality score of the corresponding order to compare both quality values
Scenario service	In case of a detected quality deviation by the Monitoring Service, the Scenario Service provides a prioritized list with possible control measures
Allocation service	This service detects planks that can be used as alternatives to fulfill the current order. This service supports swapping of planks between orders as well as procurement of stored planks
Simulation service	This service encapsulates an event-discrete simulation tool. By using the proposed control measures as input for this service, possible impacts for the order status as well as other supply chain processes are simulated

decision maker. In case of insufficient quality, the Scenario Service can be called by the decision maker to show appropriate alternatives. The alternatives are presented as a prioritized list. The order of alternatives varies depending on the deviation in quality. In this context, the Allocation Service is a subordinated service, to assist in the allocation of resources (swap or procure material). The following alternatives are offered by the Scenario Service:

- Reworking on/outside the production line: These alternatives are proposed as priorities in case of minor quality deviations.
- Swap with an non-critical order: If reworking is not possible, possible orders for swap are selected by using the Allocation Service. This means that a plank of an non-critical order and of sufficient quality is replacing the disqualified plank of the current order. The dispensed plank should still have the required quality to satisfy the non-critical order.
- Allocation or new production: If a plank cannot be exchanged, or quality deviations are too high, the Allocation Service examines whether quality checked planks are stored in other inventories in the supply chain. If so, the service can attempt to allocate such planks, otherwise a new plank has to be manufactured.

Each alternative represents a production control measure (corrective measure), in case of poor quality of planks. By selecting the first or second measure by a decision maker, the process can by controlled at this control point as planned and the underlying resources are used in an optimal way.

To assess the selected option in an integrated manner, the Simulation Service can be consulted. In the demonstrator, in particular order-based production control is analyzed by consulting the Simulation Service. On the one hand, effects related to customer delivery dates are analyzed, if orders are suspended on short notice. But also future demands of the production process can be resolved taking into account the current order status. This will be the case when orders are rescheduled as the result of selecting an appropriate control measure. By linking the captured quality data of a plank to order and process data, it becomes possible to simulate effects of different control measures in case of poor quality. The effects become transparent and constitute an appropriate basis for the decision maker.

5 Conclusions

In this contribution a Logistic Assistance System for cross-process production control depending on quality data was presented for the timber industry. It integrates a camera-based CAQ-system, which acts as quality data supplier. The integration of the LAS for continuous cross-process quality management enables the consideration of all relevant supply-chain-wide process data to choose the best measure from a holistic point of view in case of poor quality. Thus the presented combination of LAS and CAQ-systems allows for a holistic quality management approach considering effects and resources in the entire supply chain, with possible impacts on transport, stock and delivery date optimization. A coherently and aggregated visualization of large amounts of quality data as well as production control measures within the LAS supports the enterprises to maintain the required product quality as well as to comply with legal requirements.

In the presented scenario the consistent application of the quality management not only leads to the avoidance of defective goods, but also in downgrading of goods to be reused in other processes. In this manner, also additional transports and packaging material can be significantly reduced or even avoided. The presented solution was implemented on low cost hardware and cameras. These cost factors are in particular relevant for SMEs.

Concerning SMEs the next necessary steps might be to connect the LAS not only with low cost quality measuring services, but also with lean quality management systems designed for SMEs, such as the Fraunhofer QUERIS (Vieweg 2014). Such systems allow for a lean administration of quality measurement data, objectives, norms, tasks and measuring devices. This integration would be the last step of a complete SME-focused holistic quality-based process control.

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