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An Approach Towards an Adaptive Quality Assurance

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Abstract

In order to optimize the quality-related costs, the quality assurance within the production must be designed in terms of economical criteria. This design is time-consuming and cost-intensive. However, due to the increasing individualization up to lot size one, the quality assurance must be adapted in increasingly shorter cycles in order to achieve an economical optimal quality assurance at any time. The realization of an adaptive quality assurance within the production enables manufacturing companies to achieve a minimum of quality-related costs at any time despite an increasing individualization up to lot size one. Due to their high degree of swiftness regarding data acquisition, data processing and output of data in real-time, and furthermore, their capability to control physical elements with computer-based algorithms in an intertwined way, cyber-physical systems (CPS) are predestined to perform an adaptive quality assurance within the production. But, no approach towards an adaptive quality assurance, which is performed by a cyber-physical system in order to achieve a minimum of quality-related costs at any time despite an increasing individualization of manufactured products up to lot size one, has been described in literature yet. This paper fills the gap by showing an approach towards an adaptive quality assurance within the production, which is performed by a cyber-physical system.

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1. Introduction

Increasing globalization and growing scarcity of resources are leading to a rising cost pressure within manufacturing companies. To face this challenge, measures to reduce costs are essential. The enhancement of resource efficiency within the production represents one possible measure. This enhancement can be achieved through the elimination of wastes. According to the Japanese engineer Taiichi Ōno, the wastes which occur within the production can be subdivided into seven categories: Overproduction, Waiting, Transporting, Over-processing, Inventories, Moving, Making defective parts and products [1].

Faulty actions within the production are leading to the last mentioned category of wastes ("Making defective parts and products"). Typical examples for this category of wastes are scrap, replacement production and rework [2]. The effort of nonconformity represents the assessed consumption of services and goods caused by faulty actions [3]. The monetary effects of the effort of nonconformity are summarized under the term failure costs, which can be subdivided into internal and external failure costs [4,5]. Internal failure costs arise due to the effort caused by failures which are detected within the company, whereas external failure costs incur because products fail to conform to requirements after being delivered to the customer or fail to satisfy the customer [6,7]. According to a previous calculation, internal failure costs had an amount of around 11 Billion Euro in German electrical and mechanical engineering companies in 2014 [8].

The application of quality improvement approaches and methods (e.g. Six Sigma, TPM, 5S, FMEA) is a possible measure to reduce failures within the production. Processes, which are repetitive and automated can be optimized up to zero defects, but within processes performed by workers, faulty actions which are leading to failures can occur at any time. Therefore, failures can only be reduced and cannot be avoided completely.

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Faulty units which are not detected and reach downstream production stages lead to an increasing effort of nonconformity and therefore cause further costs.

On the one hand, quality control steps, which are implemented between two consecutive production stages in order to detect faulty units before they are transferred to downstream production stages, can enable the reduction of the effort of nonconformity and as a consequence lead to decreasing failure costs. On the other hand, these quality control steps are leading to an additional use of resources (e.g. quality personnel, test equipment) which in turn leads to further costs. These costs are termed appraisal costs and arise from the effort caused by quality control steps [7].

In order to achieve an optimal level of quality-related costs, within the inspection planning, production planners have to design the quality assurance within the production in terms of economical criteria by deciding about the implementation of quality control steps between production stages.

The economical savings depending on the arrangement of quality control steps within the production have already been evaluated. This evaluation is based on a sample process sequence including several production stages and different scenarios concerning the error rate of production stages. The maximum possible economical savings of internal failure costs and appraisal costs, compared to the situation that (except of a final inspection and testing step) no quality control steps are implemented, amounts 12.9 percent and in addition, the average of maximum possible economical savings of the different scenarios amounts 7.0 percent. [9]

These results highlight the importance of the arrangement of quality control steps within the production from an economical point of view. However, inspection planning within the production in terms of economical criteria proves difficult and causes a high effort due to the high number of influence quantities. In order to face this challenge, a decision-making support methodology to achieve an economical optimal solution concerning whether or not a quality control step should be implemented between two consecutive production stages has already been developed [10]. This methodology can be easily applied, provided that specific parameters (e.g. error rate of different processes, cycle time of different processes) are available and valid for each processed unit.

Commonly, the inspection planning within the production takes place in an iterative way based on empirical values. Hence, this approach is both time-consuming and cost-intensive.

The trend of increasing individual customer demands, which leads to an increasing individualization of manufactured products up to lot size one, impacts the production due to rising product variants significantly, because the higher the number of product variants, the higher the number of process variants is [11]. Furthermore, the rising number of process variants leads to an increasing probability of faulty actions which are leading to failures within the production.

Despite Fords quote “We believe […] that no factory is large enough to make two kinds of products” [12], the amount of product variants and therefore also the amount of process variants is growing continuously. As an example, for the BMW 5 series, 18 different variants of painting, 17 different variants of fabric resp. leather upholstery and 17 different variants of engines are selectable in each combination [13].

As a result of rising process variants, the economical optimal design of the quality assurance differs from product variant to product variant. Moreover, the quality assurance must be adapted in increasingly shorter cycles in order to achieve a minimum of quality-related costs at any time. The realization of an adaptive quality assurance within the production enables manufacturing companies to achieve this at any time despite an increasing individualization.

Due to their high degree of swiftness regarding data acquisition, data processing and output of data in real-time, and furthermore, their capability to control physical elements with computer-based algorithms in an intertwined way, cyber-physical systems (CPS) are predestined to perform an adaptive quality assurance within the production.

According to a definition of Lee, cyber-physical systems are integrations of physical processes and computation, whereby the physical processes are monitored and controlled by embedded computers as well as networks. Characteristically, physical processes affect computation and vice versa with the usage of feedback loops. [14]

Cyber-physical systems can be found in a wide spectrum of domains such as critical infrastructure control like electric power, traffic management, environmental control, smart buildings, etc. [15]

Based on the research of Drath, Siepmann developed a general structure for cyber-physical systems which consists of three levels [16,17]:

- Level 1: Physical Objects (e.g. tooling machines, 3D-printers)
- Level 2: Data Storages (e.g. documents, 3D-models)
- Level 3: Service Systems (e.g. algorithms, evaluations)

Within level 1 (Physical Objects), the data acquisition takes place. Level 2 (Data Storages) acts as an interface and transfers data between level 1 and level 3 (Service Systems), in which the data are processed. The processed data is transferred via level 2 as control data to level 1. [17]

The cyber part is represented by level 2 and level 3. [16]

Compared to common automation systems, cyber-physical systems enable the connectivity globally via the internet [18].

This is very important when it comes to the quality assurance because in many manufacturing companies the production and therefore also the quality assurance within the production takes place at different facilities around the globe.

There are several challenges which have to be considered when it comes to the testing of adaptive systems. These challenges have been already discussed by Siqueira et al. [19] and Eberhardinger et al. [20].

2. Need for Action

Various approaches for the optimization of the inspection planning have already been well described in literature. Overviews are given by Zhao [21] and Shewtan [22]. Further studies are dealing with quality issues in mass customization [23,24]. Moreover, Fogliatto et al., highlight, that the adaption