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# Procedure for defining the system of objectives in the initial phase of an industry 4.0 project focusing on intelligent quality control systems

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**Abstract**

Industry 4.0 describes the fourth industrial revolution, which leads to an intelligent, connected and decentralized production. A core aspect is a continuous communication between humans, machines and products during the production process enabled by cyber physical production systems (CPPS). The overall aim is to increase cost- and time-efficiency, and improve product quality, which requires a broad understanding of the enabling technologies as well as methods and tools. Within this paper, one production process (spring coiling) with three different involved value adding companies is analyzed to identify quality related production issues that shall be addressed with an intelligent condition monitoring based quality control system. The research addresses both machine related and organizational process analysis. Therefore, a comprehensive descriptive model has been developed to represent the relevant systems, their interfaces, interdependencies and influence parameters. This paper presents the procedure to develop the descriptive model, including other generated documents to define the system of objectives incorporating the technical and the value adding partners' requirements.


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*Keywords:* Industry 4.0, Quality control system, Condition monitoring, System of objectives

## 1. Introduction

Industry 4.0 describes the fourth industrial revolution, which leads to an intelligent, connected and decentralized production. A core aspect is a continuous communication between humans, machines and products during the production process enabled by cyber physical production systems (CPPS). The overall aim is to increase cost- and time-efficiency, and improve product quality, which requires a broad understanding of the enabling technologies as well as methods and tools.

Many SMCs - which are small and medium-sized companies with less than 250 employees and a turnover less than 50 million/year - in Germany face difficulties concerning adaption and application of the necessary tools and technologies of Industry 4.0 due to knowledge and organizational barriers. Therefore, there is an increasing need for supporting processes and models. This article focuses on the initial development phase of an intelligent quality control system, incorporating the analysis of the current state of quality control systems and the definition of targets and requirements for the system as well as the project stakeholders. As a primal result of the currently running three-year research project "IQ 4.0 – Introduction of intelligent quality control systems through connected value creation", the authors introduce a procedure including methods and tools that is intended to support the project core team during this initial phase.

## 2. State of the Art

Industry 4.0 stands for a new level of organization and regulation of a product's entire value chain over its life-cycle [1]. The development of Industry 4.0 comes along with a remarkable increase of performance. Studies show an increase of productivity up to 50 % [2] and more than 80 % of the examined companies that use Industry 4.0 technologies indicate an increase of efficiency [3]. More than 45 % point


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out, that the customers' satisfaction is rising and that they experience a decrease of product defects [3]. Due to a rising demand on high quality machines and products, in the next few years about 100.000 new jobs could be provided only in SMCs within Germany [4].

In practice though, the potentials of Industry 4.0 cannot be used by many SMCs because they do not know how to adapt new technology and how to find the right requirements within their company [5]. Furthermore, missing concepts for a connection with extern value adding partners prevent SMCs from using these potentials [6]. Therefore, they face the risk of falling behind the technological progress and losing competitive ability [7].

Currently, there are many concepts describing information layers (FDT, EDD, eCl@ss, IEC 61360 Series/ISO13584-42), communication layers (OPC UA: Basis IEC 62541), realization of functional layers (FDI) and consistent engineering (AutomationML, ProSTEP iViP,) which are helping companies to organize their data and information flow [8]. RAMI4.0 extends these concepts to a reference architecture-model describing lifecycles and value chains [8], but there is still a lack of research results regarding a procedure of current state analysis and definition of targets and requirements within single companies and value adding partners [10].

For an objective and automated evaluation of product and process quality as a basic element of quality control, quality describing conditions have to be monitored with measurement technologies. Often, it is impossible to monitor these conditions directly within the manufacturing-process. That is why measurable indicators have to be identified which allow a conclusion to the quality state [9]. The advantages of quality control using indicators haven't arrived in practice yet. Main reasons are the inevitable adjustments of the sensors to the specific applications as well as the complex selection and application of suitable analyzing methods to create appropriate indicators [11].

Classical database systems can be overstrained if all measured data is saved and forwarded to following levels of a quality monitoring system. In context of Industry 4.0, a decentralized, machine-oriented preprocessing of data is suggested to reduce the data quantity [12]. Big-data-solutions based on sensor raw-data accordingly lead to immense and (in parts) worthless amounts of data that necessitates further invests to the data-infrastructure [13].

The functionality of systems like Manufacturing Execution System (MES), Computer-aided Quality (CAQ), Enterprise-Resource-Planning (ERP) or workflow-systems developed strongly in the past few years. However, these systems neither include an intelligent, decentral decision logic, nor automated process-support by actuators [14]. For reasons of safety and effort, software solutions like Enterprise Application Integration or service-based system architectures haven't arrived in most companies yet, even though they are an important step to increase transparency and productivity by accomplishing a connected adding value. [15]

The increasing use of sensors extends the possibilities of gathering production data [16]. This data plays a decisive role in the context of developing innovative industrial services like predictive maintenance. New services result from the aggregation and intelligent analysis of applied machine- and environmental data [6]. However, at current state this data is hardly used [17]. The development fails at insufficient data exchange between machine manufacturer and machine user. To date, concerns regarding potential attacks to sensible data, loss of data or its misuse prevent a more intense exchange of data [18].

Looking on the before mentioned context of Industry 4.0, a central problem becomes visible: In general, Industry 4.0 solutions afford a comprehensive approach both on technical and on organizational/processual level. Usually, one single manufacturing company cannot establish new solutions due to knowledge and accessibility barriers on either technical or processual level.

In research and practice, a systematic approach for enabling Industry 4.0 solutions for SMCs – comprising manufacturer, machine developer and software supplier – is not known neither from literature nor from application. As a first step, a formalized method for the current state analysis of involved value added partners is needed to define the starting point and target state for a new Industry 4.0 quality control.

## 3. Method and Approach

The following case serves as an application example for the deduction of the process: A manufacturer of technical springs aims to improve the effectivity (availability, performance and quality) of the production system through intelligent quality control and services. The corresponding machine developer on the other hand aims to establish predictive maintenance services. A secondary target is to improve the future product generations by adapting the machine design to the real load spectrum of the production process. The software developer provides both database, data processing and interfaces to acquire, store and evaluate the sensor data. Figure 1 explains the example use-case in further detail: The quality control system is not only established within one single company, it is regarded as a cooperative process between machine user and producer.

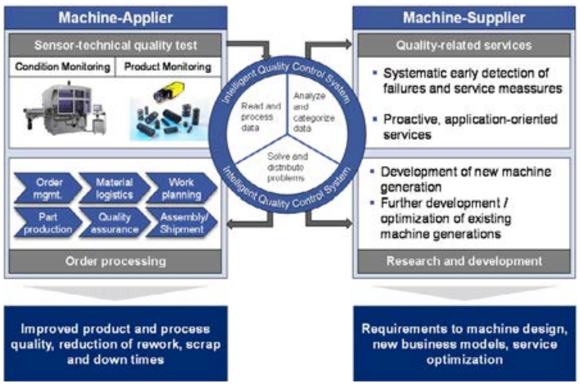


Figure 1: Example use-case with machine applier (manufacturer) and machine supplier

Within the overall project, the example case is just one of three main use cases. Both the methods and the processes for current state analysis and target state definition must suit for every one of the use cases. Additionally, the research outcome shall be transferrable to further small or medium companies (SMCs). The scientific stakeholders of the projects are three research institutes of three complementing research fields: One institute focuses on economic aspects, a second on manufacturing aspects and a third on product development aspects.

For the research process, Figure 2 shows the time schedule of activities for capturing the current situation and demand situation and the derivation of requirements. As well, the interaction between stakeholders during this process.

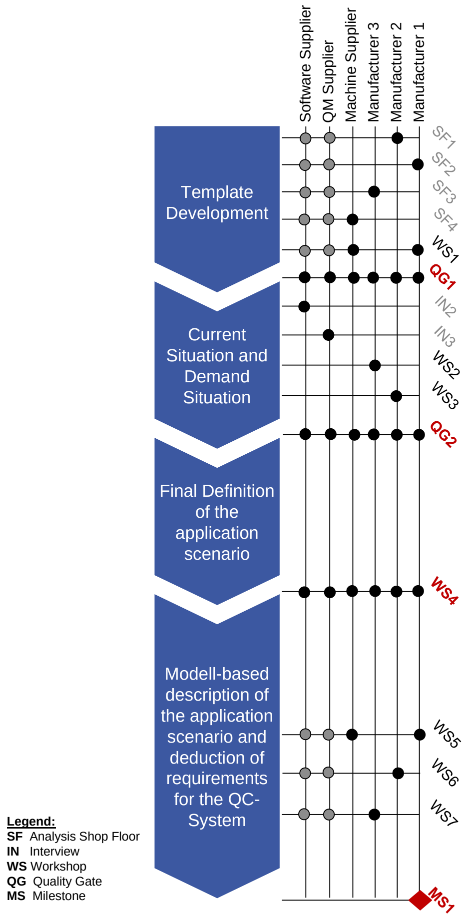


Figure 2: Time schedule and interaction between stakeholders. Manufacturer 1, Machine Supplier and QM Supplier constitute the application example.

The basic process is subdivided into four phases: At first, a generic template for the acquisition of current state and demand state is developed. Therefore, the research institutes get an insight into the shop floors of the manufacturers and the machine supplier (SF). Software and QM supplier are integrated according to the demand. Within this phase, company-specific manufacturing properties are analyzed and the manufacturing process is captured. Based on this knowledge, the institutes develop a generic acquisition template with specific variants for manufacturers, machine suppliers and QM/software suppliers. This template is evaluated within an evaluation workshop with a lead user (WS) and rolled out to all stakeholders within a quality gate (QG).

Within the second phase, the stakeholders fill the templates, which is supported by interviews (IN) and workshops. The second quality gate finalizes the acquisition phase and relevant information is shared among the stakeholders.

The third and fourth phases focus on the application scenarios, which is the very specific use case for every stakeholder (i.e. product under consideration, relevant features, quality demand). The combination of various stakeholders needs a clear and unambiguous definition of aims and deliverables. For this, a common agreement of objectives is drafted and concrete requirements for the quality control systems are derived within three further workshops.

Looking at the scope of the quality control loop for the manufacturer, four general levels of detail can be distinguished (see Figure 3) and every information about the current state, the demand and the requirements can be assigned to any of them. The central level refers to the internal machine processes. These processes are bound to the relevant manufacturing machine and define substantial parts of the product quality. The manufacturing process embeds these machine processes and widens the view from the machining to upstream and downstream processes like raw material evaluation or quality control. Order management focuses on customer requests, how they trigger the manufacturing processes and the provision of the realized product. This process integrates into the companies further processes that comprise more than just customer related order management.

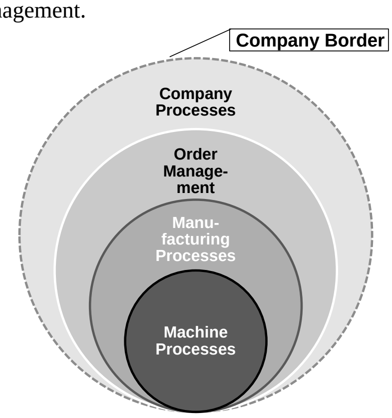


Figure 3: Four levels of detail for a company internal quality control loop

## 4. Defining the system of objectives

Based on the introduced research approach in chapter 3, a procedure for defining the system of objectives has been developed, which is introduced in this chapter. The procedure consists of a total of three phases, which are described in detail within the following sub-chapters:

1. *Initializing phase*
2. *Quality control current state analysis phase*
3. *System of objectives synthesis phase*

In the beginning of this Industry 4.0 project, the application scenario of the quality control system in development needs to be described initially. In order to be able to define precise project objectives and technical requirements a comprehensive understanding of the organizational as well as technical situation is necessary in the next step. The resulting descriptive model of the current state of quality control systems helps to identify relevant constraints, boundaries as well as interfaces between the value adding partners. By this means it serves as basis for the synthesis of precise objectives and requirements

The resulting procedure (see also Figure 4) has been developed in close cooperation with the applying industry partners and is based on three different application scenarios focusing on completely different manufacturing processes.

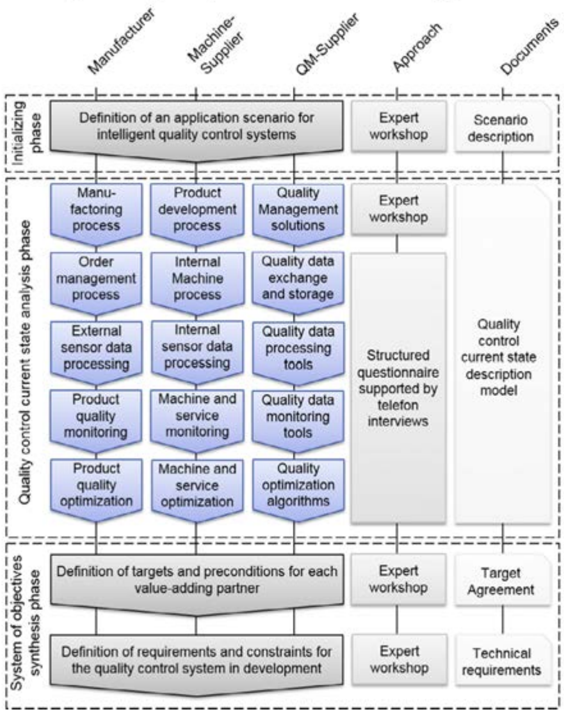


Figure 4: Process for current state analysis and target state definition in the establishing phase of an Industry 4.0 value network

### 4.1. Initializing phase

The first step on the way to establishing an Industry 4.0 value network together with other value-added partners is to define the related application scenario. The application scenario in the context of intelligent quality control systems focusses mainly on the manufactures and describes the relevant machine and support processes within the manufactures company borders (see also Figure 3). Furthermore, it describes the system in production (e.g. a compression spring) as well as the production system (e.g. a spring coil machine). In order to provide an outlook regarding intelligent quality control system in production it is also necessary to define the quality-relevant product characteristics (e.g. the spring length or diameter). They serve as basis for the measurement of the product quality and thus as the basis for the intelligent quality control system. The identification and definition of the quality-relevant product characteristics should be supported at least by qualitative (analysis of customer feedback, expert workshops) or better by quantitative data (CAQ-data review). The resulting application scenario should be summarized in one brief document in order to provide a printable overview for the following workshops in the process.

### 4.2. Quality control current state analysis phase

The aim of the current state analysis is to provide a formalized overview about already-in-use quality control systems within the Industry 4.0 value network. The resulting description model provides the basis for the identification of interfaces within the value network as well as the detailed definition of quality control target states. In order to support a systematic analysis of the current state and allowing a comparison of the resulting data a structured questionnaire is suggested for medium-sized up to large Industry 4.0 value networks. Such a questionnaire can be structured based on a generic control system scheme in order to improve the usability for the stakeholders. The resulting questionnaire structure is divided into five categories based on the five aspects according to Figure 4. In order to support an asynchronous and flexible data acquisition a database solution based on a combination of Microsoft SharePoint with InfoPath was chosen. The tool solution allows different questionnaire forms like e.g. single choice, multi choice and free text forms, file attachments as well as data export into various formats, shown in Figure 5.

*5a) Enter the most common quality problems and defined emergency measures in the table below. What process and machine sizes are affected by these measures? What actors / stakeholders are involved in this process?*

| Quality Problem | Emergency measures | Affected machine size | Involved actuator | Involved actors |
|---|---|---|---|---|
| | | | | |

*5b) Current-Situation: What measured values are used for indication of product quality?*

| Indicator | Description of indicators | Measured values |
|---|---|---|
| | | |

*5c) Target-Situation: What measured values are used for indication of product quality?*

| Indicator | Description of indicators | Measured values |
|---|---|---|
| | | |

Figure 5: Extracts of the InfoPath questionnaire

For evaluation and documentation purposes, the resulting data is transferred to a description model. In this case the model is based on a spreadsheet program, i.e. Microsoft Excel. This approach allows easy-to-use communication, filtering as well as visualization of the data. The ontology for the Excel-based template for the manufacturer is shown in the following figure 6.

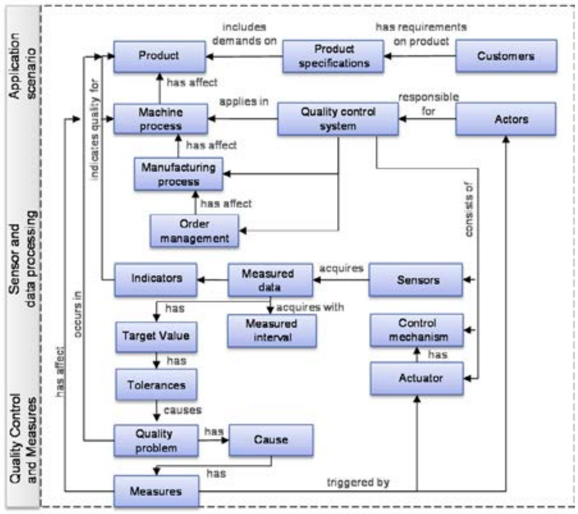


Figure 6: Ontology of the descriptive model for the manufacturer

### 4.3. System of objectives synthesis phase

Based on the defined application scenario, which briefly describes the target state of the intelligent quality control system and the Excel-based description of the current state of quality control systems for each value-added partner, the system of objectives for the quality control system is defined. This phase is divided into two steps. First, the organizational targets and preconditions (such as available resources, legal aspects, etc.) need to be clarified and documented in a target agreement. This might result in further or changed constraints during the process, which might have an impact on the technical requirements of the quality control system. Therefore, all relevant organizational constraints need to be considered a priori and clarified in the separate target agreement.

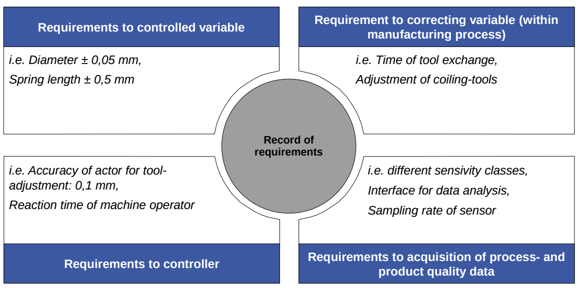


Figure 7: Visualization of the requirements document structure

In the next step the technical requirements for the quality control system in development are defined and documented in a requirements document. This resulting document is intended as a working-document supporting the requirements process during the development of the quality control system. Hereby, a top-down approach proved more efficient in all three application scenarios. This approach requires to define the overall and interface requirements for the Industry 4.0 value network first and then to focus on the individual requirements for each value-added partner within the network as well as the connected systems. Figure 7 shows the structure of the resulting technical requirements document as a part of the system of objectives.

## 5. Conclusion and Outlook

The state of the art shows a research need regarding a support procedure in the initial phase of Industry 4.0 projects, supporting definition of the system of objectives for an intelligent quality control system in development. Such a procedure requires the systematic consideration of the company internal state of quality control as well as all relevant constraints and interfaces within the value network. Therefore, a procedure is introduced based on a research project focusing on the development of intelligent quality control systems for three different application scenarios.

The introduced procedure divides into three phases: In the initializing phase the application scenario for the intelligent quality control system in development is defined and documented. In the beginning of this Industry 4.0 project the application scenario of the quality control system in development needs to be described initially. In order to be able to define precise project objectives and technical requirements a comprehensive understanding of the organizational as well as technical situation is necessary for the next step. The resulting descriptive model of the current state of quality control systems helps to identify relevant constraints, boundaries as well as interfaces between the value adding partners. Finally, the descriptive model as well as the application scenario description serve as a basis for the definition of the system of objectives for the development of an intelligent quality control system.

The introduction of an Industry 4.0 based quality control necessitates integration steps within and outside the manufacturing company. It affects sensor and actuators as well as general company processes, like information and documentation flows. Furthermore, company partners or customers have to be integrated into the development as they are all part of the overall value chain.

The introduced systematic approach has proven effective during the project in terms of providing the right information in the right quality. However, it also showed problems regarding comprehensibility of certain questions resulting in additional consultation meetings. Future work should consider the extensive usage of exemplary answers in the questionnaire in order to improve efficiency and avoid these iterations. On the tool side there is also potential for improvement. The combination of Microsoft SharePoint and InfoPath turns out to be instable in certain situations resulting in loss of data during acquisition process.

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