Proceedings in Manufacturing Systems
Proceedings in Manufacturing Systems, Volume 14, Issue 2, 2019, 43-48 ISSN 2067-9238

RELEVANT DATA WHEN IMPLEMENTING TOOLS OF QUALITY IN CYBER-PHYSICAL SYSTEMS

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Abstract: *Tools of quality aim to increase the quality in manufacturing systems and hence, maintain or even improve the competitiveness of enterprises. A promising approach to gain the effectiveness of tools of quality is the implementation of these tools in cyber-physical systems. However, there is a gap of knowledge when it comes to such an implementation – in particular concerning the relevant data of the tools of quality. In order to deal with this issue, this paper presents results from an examination of seven tools of quality regarding their relevant data when it comes to an implementation in a cyber-physical system. Firstly, different key characteristic of cyber-physical systems are carved out, which have to be considered. Then, seven basic tools of quality are examined in detail in order to identify their specific relevant data. The identified data are sorted into the categories basic data, input data and output data. Subsequently, an approach for a systematic identification of data flows between the tools of quality based on a pairwise evaluation is described. Moreover, major data flows between tools of quality are proposed. Finally, findings of a practical implementation of tools of quality in a cyber-physical system are presented. It has been proven that a real-time capability as well as a location-independence can be achieved when tools of quality are implemented in cyber-physical systems under consideration of the data identified in this paper.*

Key words: *Cyber-physical systems, production optimization, quality management, data examination, quality improvement, manufacturing systems.*

1. INTRODUCTION

Delivering products with a proper quality to customers is an essential goal for manufacturing enterprises in order to stay competitive in a highly globalized economy. The implementation of tools of quality aims to support achieving this goal and hence, represents a promising measure to maintain or even improve the competitiveness of enterprises.

Within the past few decades, quality experts developed many different tools of quality. Due to various advantages, like simple applicability, promotion of creativity and visualization of interrelationships as well as problems, these tools became an integral element of the quality management system in numerous manufacturing enterprises worldwide [1]. However, despite their advantages, tools of quality have some disadvantages. Major disadvantages are limited informative value of single tools of quality and the occasionally need of high data quantity [2].

In order to compensate the first disadvantage mentioned above, the tools of quality should be implemented as a set of tools. Theden and Colsman as well as Kamiske propose to implement three tools for fault detection (check sheet, control chart and histogram) firstly and four tools for fault analysis (cause-and-effect diagram, scatter diagram, Pareto chart and brainstorming) subsequently whereas these tools are summarized under the term “Seven Basic Tools of Quality” [2, 3, 4].

The second disadvantage mentioned above can be compensated by implementing tools of quality in cyber-physical systems. According to Lee, these systems are integrations of computation and physical processes, which are monitored and controlled by embedded computers as well as networks and additionally, physical processes affect computation and vice versa with the usage of feedback loops [5]. Cyber-physical systems record data from the physical world immediately by using sensors to evaluate the behavior of physical systems and interact with the digital respective the physical domain actively and reactively [6]. Therefore, a cyber-physical system seems to be a high potential technology to compensate the aforementioned disadvantage of the need of high data quantity when it comes to the implementation of tools of quality.

In spite of these obvious benefits, the implementation of tools of quality in cyber-physical systems especially regarding the necessary data, which is a crucial aspect, has not yet been described in literature. This in turn leads to a gap of knowledge when it comes to such an implementation in manufacturing enterprises. Especially the awareness of relevant data for implementing basic

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tools of quality in cyber-physical systems is essential in general.

Against this background, this paper presents for the first time the results from an examination of seven tools of quality regarding their relevant data when it comes to an implementation in a cyber-physical system. Firstly, key characteristics of cyber-physical systems are pointed out. After that, the single tools of quality are examined regarding relevant data when implemented in a cyber-physical system in general. Based on this, it is described how the flow of data between different tools of quality can be identified for specific applications. After that, the practical implementation of tools of quality in a cyber-physical system based on the identified data is explained briefly. Finally, a conclusion is drawn and an outlook on further research is given.

2. KEY CHARACTERISTICS OF CYBER-PHYSICAL SYSTEMS

In this section, different key characteristic of cyber-physical systems are carved out, which have to be considered when implementing tools of quality.

First of all, cyber-physical systems can be structured in general into three levels [7, 8]:

- Level 1: Physical objects (e.g. tooling machines).
- Level 2: Data storages (e.g. documents).
- Level 3: Service systems (e.g. algorithms).

The data acquisition takes place in level 1. Level 2 is an interface between level 1 and level 3 and transfers the acquired data to level 3 where the data processing takes place before the outcomes are transferred to the physical objects via level 2 [8].

A further notable key characteristic of cyber-physical systems is the usage of data and services, which are available worldwide [6]. This availability becomes more and more important due to the increasing globalization. In such a way, the worldwide connectivity and hence location-independence distinguishes cyber-physical systems clearly from common automation systems [9].

Moreover, cyber-physical systems compute in real-time which makes these systems highly dynamic [10]. This ensures a high degree of swiftness concerning the acquisition, the processing and the output of data [11].

3. EXAMINATION OF RELEVANT DATA

This section starts with the definition of data categories. Then, the relevant data when implementing tools of quality in a cyber-physical system are shown before flows of data between the tools are made subject of the discussion.

3.1. Definition of data categories

The definition of data categories is based on the general structure of cyber-physical systems. Three types of basic data have to be differentiated:

- Basic data: Data characterizing rules and attributes to perform calculations concerning tools of quality
- Input data: Data covering information acquired from a physical process
- Output data: Data transferred to a physical process to change a process behavior

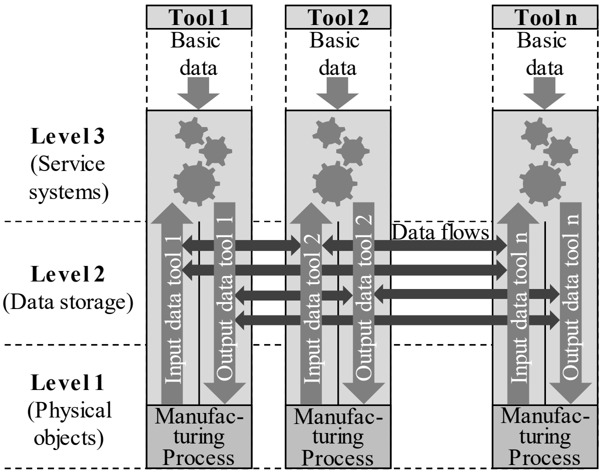


Fig. 1. Data categories in the structure of cyber-physical systems (based on [7, 8]).

As shown in Fig. 1, every implemented tool of quality extends over the entire cyber-physical system. In level 1, input data is acquired continuously. These data derive directly from the manufacturing process and represents information for the operational execution of the tools of quality, which in turn takes place in level 3. Additionally, basic data, like boundary conditions, have to be supplied prior to the operational execution of the tools of quality. The results from the operational execution of the tools of quality are transferred from level 3 via level 2 to level 1 and handed over to the manufacturing process to control process properties.

Since data of all three categories – the basic, the input as well as the output data – can be shared by different tools of quality, data flows may occur in level 2 between the tools of quality. These data flows will be discussed later.

3.2. Relevant data of single tools of quality

In the following, single tools of quality are explained briefly before their specific basic, input as well as output data are pointed out. The tools taken into account represent together the “Seven Basic Tools of Quality” based on Theden [2] and Colsman [3] as well as Kamiske [4].

Check sheet: The purpose of a check sheet is to record and depict attributes (e.g. failures) concerning type and number of occurrence [4]. According to Kane, check sheets can be subdivided into the following types [12]:

- Classification: An attribute, like a failure mode, is subdivided into categories
- Location: With this type, physical locations of attributes are recorded
- Frequency: This type quantifies either the occurrences of both the absence and presence of specific attributes or the number of occurrence of an attribute on a part
- Measurement scale: The results of measurements are filled in a predefined scale
- Check list: Single items to complete a task are listed and checked after accomplished

Table 1

Relevant data – Check sheet

Basic data	Attributes to be examined (e.g. failure modes)
	Features of the potential attributes [a] (e.g. location and/or period of occurrence)
Input data	Occurred attributes [b]
	Features of the occurred attributes [a,b]
Output data	Number of occurred attributes (subdivided into features [a])

[a] If necessary. Depends on the type and desired information content of the particular check sheet.

[b] With regards to the basic data.

For the implementation in a cyber-physical system, the identified basic, input as well as output data relating to a check sheet is shown in Table 1.

Control chart: This tool of quality is used to monitor the temporal behavior of processes. It describes the process behavior graphically, deploying defined boundaries for actions and providing the opportunity to identify trends of process deviation at an early point of time [13]. As shown in following Fig. 2, a typical control chart consists of a center line which indicates the average value and different limit lines, like control limits which indicate an out-of-control process, when exceeded by the recorded values [14].

Various types of control charts and corresponding calculations for relevant data (e.g. values for upper and lower limits) have already been well described in literature and hence, are not described in more detail here. For instance, Holmes [14], Ryan [15] and Linß [16] give overviews about different types of control charts and calculations. Moreover, regarding the relevant data, it is focused on Shewhart control charts since they are widely applied in industry. Table 2 shows the identified basic, input as well as output data relating to a Shewhart control chart.

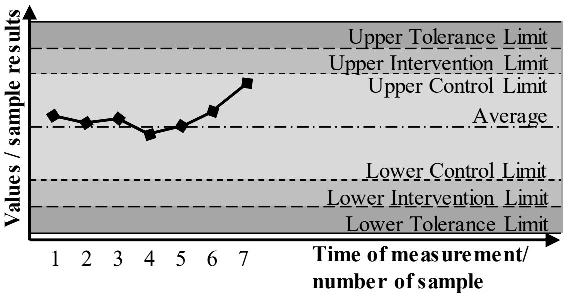


Fig. 2. Structure of a typical control chart with recorded values / sample results (example).

Table 2

Relevant data – Shewart control chart

Basic data	Characteristic to be examined
	Sample size
	Sample frequency
	Average value for center line
	Values for upper and lower limits
Input data	Measured values of single units [a]
Output data	Recorded values / sample results [a]

[a] Inclusive time of measurement / number of sample.

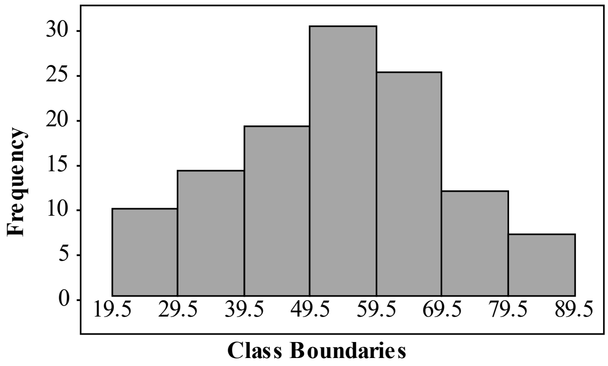


Fig. 3. Histogram (example) [15].

Histogram: This tool of quality aims to visualize the frequencies of classified data [4, 15]. A histogram is a valuable tool to consolidate and evaluate empirical observations [16]. Based on the outcomes of a histogram, statistical indicators (e.g. standard deviation) can be calculated. However, this will not be investigated since histograms aim solely a structured visualization of data. As shown in Fig. 3, a typical histogram is a bar chart with the class boundaries on the x-axis and the class frequencies on the y-axis [15].

Prior to the operational execution of this tool of quality, the characteristic to be examined has to be defined. Moreover, the sample size has to be set before this execution. The number of classes can be defined in consideration of the sample size whereas the following rule applies: the higher the sample size, the higher the number of classes. In turn, the class boundaries can be calculated from the amount of classes and the smallest as well as the highest measured value from the inspection of single units. [4, 16] These values are input data while the class boundaries and the frequencies of classes, which result from all measured values, are output data, see Table 3.

Cause-and-effect diagram: The cause-and-effect diagram represents a tool to analyze a problem by structuring potential causes, which can effect a specific problem, into primary and secondary causes and represent them in a systematic overview, see Fig. 4. This

Table 3

Relevant data – Histogram

Basic data	Characteristic to be examined
	Sample size
Input data	Measured values of single units
Output data	Class boundaries
	Frequencies of classes

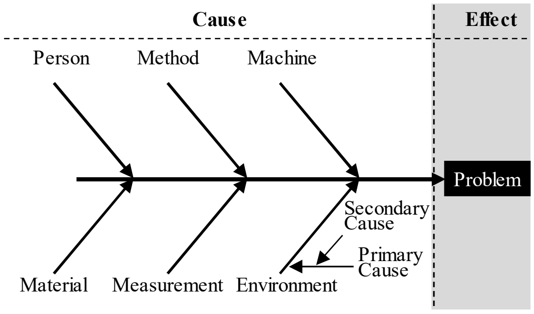


Fig. 4. Structure of a cause-and-effect diagram.

tools aims to identify the causes that actually effect a specific problem (e.g. a product defect). At the highest level, causes can be categorized as follows: People (resp. Man), Method, Machine, Material, Measurement and Environment [4, 12, 17, 18].

The operational execution of this tool bases on a specific problem. Thus, a specific problem to be examined should be given as basic data before executing the cause-and-effect diagram. As supplementary basis data, different levels of causes and potential causes related to these levels, like the highest-level causes shown in Fig. 4, have to be predefined initially. This collection of potential causes (structured into the predefined levels) is extended with further potentials as input data during the operational execution of the tool. Finally, all potential causes – initially predefined as well as gathered during the operational execution – structured according to the predefined levels represent the output data of this tool of quality (Table 4).

Scatter diagram: Scatter diagrams aim to point out correlations – in its simplest form – between two variables [4, 15]. They are applied to investigate whether and how potential causes influence quantities (e.g. failures) [1]. This is based on the inspection of a sample and supports the decision to confirm or to reject hypotheses about cause-and-effect relationship [16].

Fig. 5 illustrates an example scatter diagram with a positive correlation between the two variables based on the inspection of a sample consisting of 30 units. Usually, within two-dimensional scatter diagrams the vertical axis shows the variable that is supposed to be dependent on the variable of the horizontal axis [15]. The correlation coefficient provides a measure of the degree of dependence [4, 16]. However, since this tool of quality aims to visualize dependencies instead of describing them mathematically, a calculation of dependencies is not taken into account at this point.

As seen in Table 5, the variables to be examined and the sample size represent the basic data of this tool. The measured values of the variables that derive from the inspection of single units are input data for this tool whereas all recorded values of a considered sample are output data.

Table 4

Relevant data – Cause-and-effect-diagram

Basic data	Problem to be examined
	Levels of causes
	Potential causes [a]
Input data	Potential causes [a]
Output data	Potential causes (structured according to the levels of causes)

[a] Related to the predefined levels of causes.

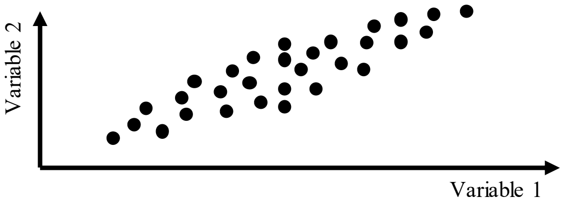


Fig. 5. Structure of a scatter diagram.

Table 5

Relevant data – Scatter diagram

Basic data	Variables to be examined
	Sample size
Input data	Measured values of single units
Output data	Recorded values

Pareto chart: This tool of quality represent a chart to visualize the cause of effects (e.g. problems) respectively the categories of causes according to their order of importance of their impact [4].The frequency of detected causes respectively of categories of causes is indicated primarily with bars. However, compared to a histogram, bars within a Pareto chart are arranged in descending order [15]. It is based on the Pareto principle at which circa 80 percent of effects (e.g. problems) are affected by circa 20 percent of effects (e.g. failures).

Figure 6 shows a typical Pareto chart which includes in addition to the bars, a line indicates the frequencies accumulated.

In order to identify relevant data for this tool of quality, it is expedient to have a look at the following approach for setting up Pareto charts [16]:

- Definition of causes / categories of causes.
- Definition of quantity to measure and describe the effects (e.g. frequency, costs).
- Recording of detected causes.
- Sorting the causes / categories of causes according to their order of importance of their impact.
- Graphical representation.
- Decision about measures to be taken for improvement.

Based on this approach, the following data are relevant when it comes to the implementation of a Pareto chart in a cyber-physical system (Table 6).

Brainstorming: This tool of quality purposes the idea generation, the increasing of creative efficacy and furthermore the finding of problem solutions, individually

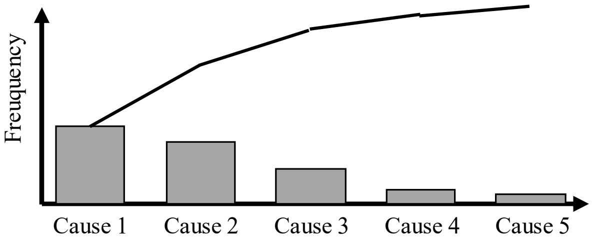


Fig. 6. Structure of a Pareto chart.

Table 6

Relevant data – Pareto chart

Basic data	Causes / categories of causes to be examined
	Quantity to measure and describe the effects (e.g. costs per detected cause)
	Sample size
Input data	Detected causes / categories of causes
Output data	Frequency of recorded causes / categories of causes (sorted according to their order of importance of impact)

Table 7

Relevant data – Brainstorming

Basic data	Problem to be examined
	Criteria to structure and evaluate proposed solutions
Input data	Potential solution
	Evaluation results of potential solutions [a]
Output data	Potential solutions (structured and sorted according to the criteria to structure and evaluate proposed solutions)

[a] With regards to the basic data.

or in a group [19]. Kamiske proposes a two-stage approach for applying this tool [4]:

- Creative Phase: Collection of a large amount of potential solutions for a specific problem
- Evaluation Phase: Structuring and evaluation of proposed solutions

Compared to a traditionally moderated brainstorming, the applying of brainstorming in a computing environment as within cyber-physical systems offers several benefits, like higher anonymity and increased media speed [20]. Table 7 shows the identified basic, input as well as output data relating to this tool of quality.

3.3. Data flows between the tools

Due to the implementation of the basic tools of quality in a cyber-physical system, data can be transferred swiftly from one to another tool. This has the great advantage, that some data can be used multiple, which in turn leads to a higher efficiency since synergy effects can be leveraged.

A systematic identification of data flows between the tools of quality, which are supposed to be implemented in a cyber-physical system, can be achieved by an evaluation of all pairs of relevant data. A table for this evaluation is shown partially on the left side of Fig. 7. Within every pairwise evaluation regarding potential data flows between the tools of quality, the procedure shown on the right side of Fig. 7 should be considered.

In Fig. 8, potential major data flows are proposed. They derive from an evaluation of pairs of the identified basic, input as well as output data of the single tools of quality considered in this paper. In some cases it is necessary, to transform the data within a data flow via data processing, like filtering or merging data. This data processing will not be investigated in detail because this depends strongly on the individual application of the tools of quality.

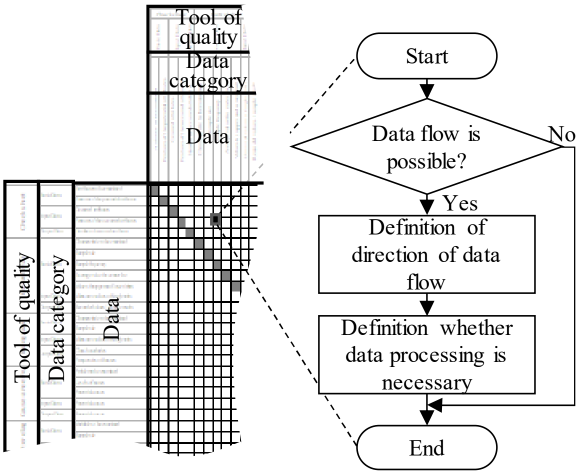


Fig. 7. Pairwise evaluation.

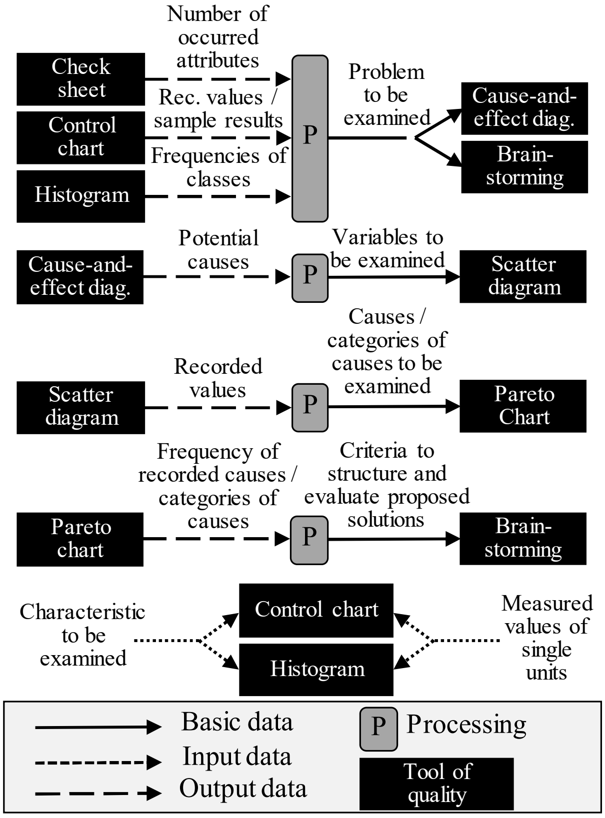


Fig. 8. Proposed major data flows between the tools of quality.

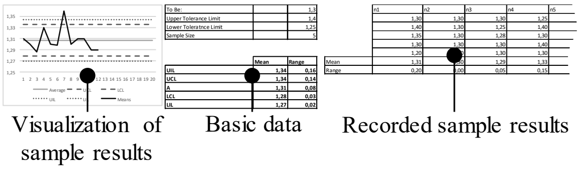
4. PRACTICAL IMPLEMENTATION

Based on the identified basic, input as well as output data, the tools of quality considered in this paper have been implemented in a cyber-physical system executed in the learning factory of the Chair Manufacturing and Remanufacturing Technology of the University of Bayreuth, see Fig. 9.

The practical implementation of the cyber-part took place in MS-Excel whereas a four-stage manual assembly process represents the physical part of the cyber-physical system. The product to be assembled is a mechanical device to position single screws for a simplified grapping of screws e.g. by a robotic screw driving system. In the first test run, 60 of these products were assembled in total.

In Fig. 10, the output screen of an implemented control chart is partly illustrated. Besides a tabular overview of the recorded sample results, a visualization

Fig. 9. Learning Factory.



To Be:		1,3
Upper Tolerance Limit		1,4
Lower Toleratnce Limit		1,25
Sample Size		5

	Mean	Range
UIL	1,34	0,16
UCL	1,34	0,14
A	1,31	0,08
LCL	1,28	0,03
LIL	1,27	0,02

	n1	n2	n3	n4	n5
	1,30	1,30	1,30	1,25	
	1,40	1,30	1,25	1,40	
	1,35	1,30	1,28	1,30	
	1,30	1,30	1,30	1,40	
	1,20	[illegible]	1,30	1,30	
Mean	1,31	[illegible]	1,29	1,33	
Range	0,20	[illegible]	0,05	0,15	

Fig. 10. Output screen (control chart).

of these results is output. Moreover, the output screen shows the basic data which were defined before executing this tool. For reasons of clarity the specification about the implemented single tools of quality are not described in detail here.

The first test run provided encouraging results: It has been proven that a real-time capability as well as a location-independence can be achieved under consideration of the data identified in this paper. Therefore, the operational execution of basic tools of quality in a cyber-physical system has great potential for manufacturing enterprises and the data as well as the data flows pointed out in this paper support the implementation of tools of quality in cyber-physical systems. However, at the moment, only qualitative results can be presented. A quantitative assessment requires a much longer test run but is part of further research.

5. CONCLUSION AND FURTHER RESEARCH

This paper examines for the first time single tools of quality regarding their relevant data when it comes to the implementation of these tools in a cyber-physical system. Moreover, the paper describes how data streams, which should be established in order to benefit from the advantages of cyber-physical systems, can be identified systematically for a specific application. The examined relevant data, the approach to identify data flows systematically and the proposed major data streams can be used as a basis within the implementation of tools of quality in a cyber-physical system in industrial environment.

As part of further research, the data processing within data flows will be investigated in detail for individual applications. Furthermore, a long-term test run will take place in order to achieve quantitative results. Moreover, additional tools of quality will be evaluated regarding their specific basic, input as well as output data in order to extend the knowledge base of relevant data when it comes to the implementation of tools of quality in a cyber-physical system.

REFERENCES

[1] H. Brüggemann, P. Bremer, *Grundlagen Qualitätsmanagement: Von den Werkzeugen über Methoden zum TQM*, Springer Vieweg, Wiesbaden, 2015.

[2] P. Theden, *Handbuch QM-Methoden: Die richtige Methode auswählen und erfolgreich umsetzen* (Handbook QM-Methods: Selecting and implementing successfully the correct method), G.F. Kamiske (Ed.), Hanser, München, 2015, pp. 671–686.

[3] P. Theden, H. Colsman, *Qualitätstechniken: Werkzeuge zur Problemlösung und ständigen Verbesserung*, Hanser, München, 2013.

[4] G.F. Kamiske, J.-P. Brauer, *Qualitätsmanagement von A bis Z: Erläuterung moderner Begriffe des Qualitätsmanagements,* Hanser, München, 2011.

[5] E.A. Lee, *Cyber Physical Systems: Design Challenges*, 11th IEEE Symposium on Object Oriented Real-Time Distributed Computing (ISORC), pp. 363–369, Orlando, May 2008, IEEE, New York City.

[6] M. Briy, *Cyber-Physical Systems: Innovation durch software-intensive eingebettete Systeme* (Cyber-Physical Systems: Innovation by software-intensive embedded systems), M. Broy (Ed.), Springer Verlag, Berlin, 2010, pp. 17–31.

[7] R. Drath, *Agenten im Umfeld von Industrie 4.0* (Agent in the environment of industry 4.0), B. Vogel-Heuser (Ed.), sierke, Göttingen, 2014, pp. 47–56.

[8] D. Siepmann, Einführung und Umsetzung von Industrie 4.0: Grundlagen, Vorgehensmodell und Use Cases aus der Praxis (Introduction and realization of industry 4.0: Basics, approach and use cases from practice), A. Roth (Ed.), Springer Verlag, Berlin, 2016, pp. 17–34.

[9] VDI, VDE, *Cyber-Physical Systems: Chancen und Nutzen aus Sicht der Automation*, Düsseldorf, 2013.

[10] L. Sha, S. Gopalakrishnan, X. Liu, Q. Wang W, *Cyber-Physical Systems: A New Frontier*, IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing, pp. 1–9, Taichung, June 2008, IEEE, New York City.

[11] S. Schötz, S. Butzer, P. Molenda, T. Drews, R. Steinhilper, *An Approach Towards an Adaptive Quality Assurance*, Procedia CIRP, Vol. 63, 2017, pp. 189–194.

[12] V.E. Kane, *Defect Prevention: Use of Simple Statistical Tools*, Dekker, New York, 1989.

[13] R. Schmitt, T. Pfeifer, *Qualitätsmanagement: Strategie – Methoden – Techniken*, Carl Hanser Verlag, München, 2015.

[14] D.S. Holmes, *Introduction to SPC*, Stochos, Schenectady, 2003.

[15] T.P. Ryan, *Statistical Methods for Quality Improvement*, Wiley, Hoboken, 2011.

[16] G. Linß, *Qualitätsmanagement für Ingenieure*, Carl Hanser Verlag, München, 2018.

[17] R.A. Munro, *Six Sigma for the Shop Floor: A Pocket Guide*, Quality Press, Milwaukee, 2002.

[18] C.A. Ericson II, *Concise Encyclopedia of System Safety: Definition of Terms and Concepts*, Wiley, Hoboken, 2011.

[19] C. Wilson, *Brainstorming and Beyond: A User-Centered Design Method*, Elsevier, Oxford, 2013.

[20] O. Petrovic, O. Krickl, *Traditionally-moderated versus computer supported brainstorming: a comparative study*, Information & Management, Vol. 27, 1994, pp. 233–243.