Advances in Production Engineering & Management **ISSN 1854-6250**
Volume 12 | Number 4 | December 2017 | pp 388–400 Journal home: apem-journal.org
https://doi.org/10.14743/apem2017.4.266 Review scientific paper

An overview and evaluation of quality-improvement methods from the manufacturing and supply-chain perspective

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A B S T R A C T

In recent years, besides high productivity of the manufacturing process, quality issues (including safety requirements and cost efficiency) have both become major market drivers. In order to meet all the above objectives, so as to achieve competitive advantages, a number of quality techniques need to be implemented within the manufacturing process. Starting from the general manufacturing model and presenting a supply-chain philosophy, this paper provides an overview of the quality tools and methods such as quality techniques and links to manufacturing process quality and manufacturing cost-effectiveness; it focuses on manufacturing processes and perceived quality problems associated with the supplier's quality issues. Additionally, the impact of the component supplier on the overall quality of the final product needs to be distinguished from the impact of the manufacturing process. Based on the model of the general manufacturing process the authors propose methods of effective deployment for the most common quality methods and tools within different manufacturing areas. In the discussion the authors propose certain quality techniques to improve the key performance indicators (KPI) within the manufacturing process.

A R T I C L E I N F O

Keywords:
Manufacturing
Supply chain
Quality methods
Quality tools
Quality function deployment (QFD)

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Article history:
Received 29 May 2017
Revised 25 September 2017
Accepted 22 October 2017

1. Introduction

Customers define the functional requirements of products, while manufacturers need to respond appropriately and provide the market with products that customers will accept [1]. Customer requirements or trends in the market change quickly; therefore, manufacturers are forced to reorganize internal processes and quickly respond to the changing needs of the market [2]. This study shows that supplier management is essential to ensure product/service quality [3]. To achieve stability in the relationship, companies should choose suppliers based on their quality and reliability, encourage their participation in the design of products and try to improve the suppliers' awareness of the importance of quality. Quality assurance is one of the most essential processes in the supply chain; therefore, specific quality methods and tools need to be employed. Since there are many different methods and tools available, the characteristics need to be assessed, benefits and weaknesses need to be exposed, and optimal application areas have to de defined.

2. Quality assurance and manufacturing processes

A manufacturer can only be effective if the level of quality perceived by the buyers of its products is achieved. Since all production processes within manufacturing companies are supported by supply-chain management, it is crucial to understand the quality of the supply-chain network. Suppliers have taken on the responsibility to constantly ensure an adequate level of quality, which in turn has resulted in an overall increase in the reliability of products [4, 5].

2.1 General manufacturing model

A supply-chain network is supplying material components to a manufacturing company, which is converting them into final products – the final products are then sold to the final customer. An on-going selling process is only possible if the manufacturing company is able to produce products that are fulfilling requirements related to quality and functionality, defined both by the customer and local legislation [5]. Quality supervision is carried out by the buyers of components (manufacturing companies), which by using the (un)announced audits of processes and products have overseen the work of suppliers and therefore provided an appropriate level of product quality, which is essential for the satisfaction of end customers. Some manufacturers, despite the implemented ISO standards, started to demand that their component suppliers comply with specific quality requirements, which they define additionally by themselves. This requirement stems from the conviction of manufacturers that by defining and realizing specific quality requirements they will, to the greatest extent, meet the expectations of the customer for their products [7]. Globalization has resulted in the best tools and methods for the optimization of business processes, tools which have been refined and positively proven in various parts of the world [8]. With the aim of maximizing the profits of the business, there is a strong motivation for the manufacturer to employ the cost-effective implementation of internal company processes [9].

The recommended actions to improve the level of manufacturing quality [10] are as follows:

- collect all the necessary information about the cost of poor quality and display it in a transparent manner,
- define effective measures to improve each individual cost and determine the people responsible and the dates of implementation,
- regularly and promptly communicate information about the cost of poor quality and improvement actions to the employees,
- modify processes to prevent the detected problems from repeating and continuously analyse the situation of low-quality costs and implement improvement measures,
- motivate employees in the company so that they, on their own initiative, contribute to the implementation of preventive measures in the company processes.

Taguchi [11] summarized the costs of poor quality with a sketch of an iceberg, the visible part of which is obvious, while the hidden part becomes visible only after a thorough analysis. *Visible part*: administrative costs of a customer-complaints procedure, costs of claimed product's testing, costs of claimed product's rework, and costs of claimed product's scrap. *Hidden part*: costs of product's special freight, costs of labour overtime, costs of the subsequent development of non-conforming products; costs of the loss of production capacities, costs of sorting claimed products, and costs of the loss of the customer.

Based on the findings above we present a general manufacturing process model where the materials are provided by a supply-chain network (Fig. 1, left-hand side) to the manufacturing company (Fig. 1, in the middle), which is manufacturing the final product for an end customer (Fig. 1, right-hand side). The model emphasizes the importance of quality checks, which are crucial to achieving the required quality level. Quality checks are performed internally through the company's internal quality audits and/or externally through quality audits performed by local authorities and/or customer representatives.

The following two quality-assurance goals are taken into consideration:

- The first goal is to ensure internal quality standards: blue lightning icons are indicating the internal quality checks, which are independently executed within the supply-chain network and the manufacturing company,
- The second goal is to ensure compliance with the customer and legal requirements: the red loop icon is indicating an external quality check within the supply-chain network, executed by the manufacturing company.

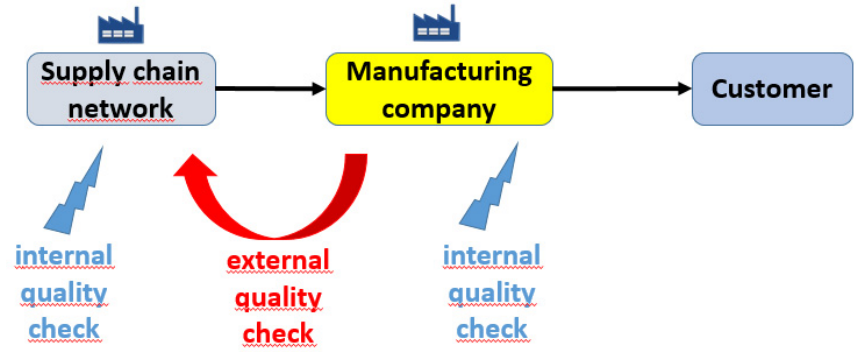

Fig. 1 A general manufacturing model

2.2 Quality assurance within a supply chain

Manufacturing companies have a tendency to deliver products with technical specifications that are defined by a customer. This is only possible within a faultless manufacturing process, where constant monitoring over the manufacturing parameters is applied. The same philosophy is valid for a supply-chain network consisting of multiple suppliers (*tier one* and *tier two*), which are delivering components in the following sequence: tier two is supplying tier one, while tier one is supplying the manufacturer [4, 6, 13].

There is a material stream between the tier suppliers and the manufacturing company (Fig. 2), where quality-performance monitoring has to be applied in order to ensure the required level of the component and consequently the final product quality [6].

Market requirements are met when an adequate quality level is integrated and the quality traceability is ensured in the manufacturing process, which needs to produce products with an acceptable cost. This known fact cannot be linked just to the manufacturer's processes, but to the supplier processes as well – they both need to ensure that the quality standards are met, otherwise the products will fail on the market. The agreed properties of the final product can only be achieved if the supplier's component with the proper quality is used in a well-designed (also in relation to the supplier's component) manufacturing process. Due to the fact that the majority of manufacturers outsource component production, many suppliers are forced to invest in methods and systems to improve the quality of their production, which also includes a traceability system that provides an insight into the manufacturing history of each individual component. Quite often the production facilities are arranged at different locations in the factories – subassemblies and manufacturing processes are assigned to certain production checks, named *final quality control*, which are providing the digital data by means of which the history of production for each product can be determined in the control system of production [14-16].

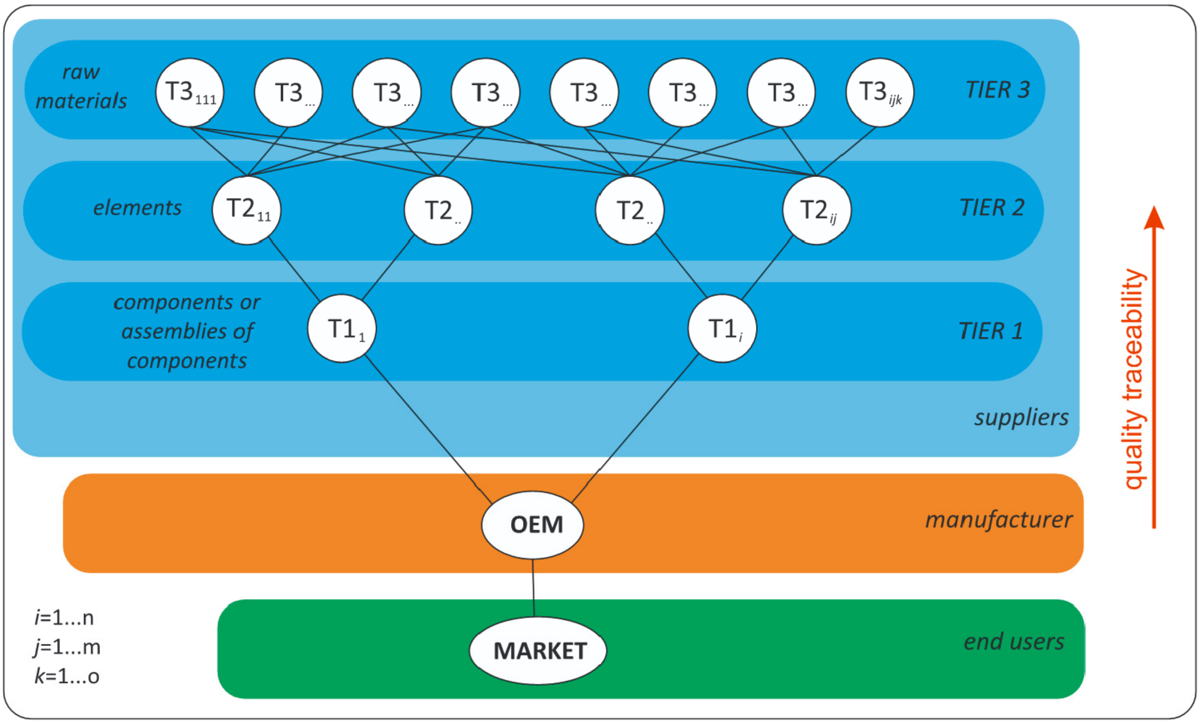

Fig. 2 An example of a supply chain [6]

3. Evaluation of common quality methods and tools

The concept of providing quality products includes not only the fulfilment of customer needs, but also the ability to maintain and service those products at low cost. The quality-assurance system was originally developed by the Toyota Motor Corporation and was later named the Toyota Production System. The high level of quality of their vehicles was achieved through the standardization of processes and the establishment of effective communications within the departments of the company. The activities of the staff were focused on obtaining information by audits, inspections, tests and analyses of a variety of development and production processes. Due to a decrease in the value of stocks of materials Toyota needed to ensure high flexibility in manufacturing, which followed the volume of vehicle sales, while other car manufacturers produced vehicles on stock, but then subsequently failed to sell them. The methodology of obtaining information through assessment, testing and inspection, and the creation of flexible production, was later named lean production [17].

3.1 Quality tools

The seven basic quality tools were defined by Kaoru Ishikawa and used for problem-solving purposes. Ishikawa is of opinion that 90 % of all issues could be solved using seven quality tools, which are presented in Table 1 [18, 19].

The characteristics of all seven tools are presented, and the strengths and weaknesses are highlighted. Based on a general manufacturing model, presented in Fig. 1, potential manufacturing areas are presented.

Table 1 Seven quality tools [4, 7, 13, 17, 19]

Quality tool	Characteristics	Strengths	Weaknesses	Areas of application
Cause-and-effect diagram	identifies the different types of possible causes that have led to a specific problem or effect	• visualizes relationships between causes and effects • visualizes dependent relationships	• the tool is not defining a proper solution (causes are only transparently presented) • the probability level of the shown causes is always presented as equal	Supply-chain network, manufacturing company
Flow chart	workflow mapping by showing the order that activities and decisions occur	• problem can be effectively analysed (cost reduction)	• if alterations are required the flowchart might require re-drawing completely (waste of time)	manufacturing company
Control table	pre-prepared table for data collection and analysis	• structural presentation of data	• additional data processing is needed	Supply-chain network, manufacturing company
Control chart	provides a graphical representation of the trend of the observed process and includes upper and lower limits of values	• good visualization • values of the control limits are added and mean line	• instructions are needed prior to interpretation of the results	Supply-chain network, manufacturing company
Histogram	visualizes the distribution of the process, or the frequency of occurrence of each value of the process	• data can be easily read • works well with large ranges of information	• inconvenient when comparing multiple categories	Supply-chain network, manufacturing company
Pareto analysis	diagram shows the causes ranked from most frequent to least frequent; this classification allows a focus on the main causes	• organizational efficiency • improved decision making	• focus on the past • inaccurate problem scoring	Supply-chain network, manufacturing company
Scatter plot	visualizes the interdependence of variables and defines the relationship between the dependent and independent variables	• ability to show whether correlations between variables are positive or negative; linear or non-linear; high, low or n/a • very convenient when identification of matching of different statistical data is needed	• the tool is not appropriate for observing more than two variables • discretization of values	Supply-chain network, manufacturing company

3.2 Quality-assurance methods

Quality management within the industry is not effective without an appropriate knowledge of quality methods. Despite the fact that many different quality-assurance methods are applied in many different industries, Table 2 represents six quality-assurance methods that are the most commonly used during the optimization of production processes [7, 20].

Table 2 Most commonly used quality-assurance methods [4, 7, 11, 17, 19]

Quality Method	Characteristics	Strengths	Weaknesses	Areas of application
Quality Function Deployment (QFD)	identifies the customers' needs and expectations, and then defines the correct responses to them.	• higher quality • lower development costs	• not universal problem-solving method • time consuming	manufacturing company
Statistical Process Control (SPC)	enables understanding of machine or process capability during the production process	• early detection and prevention of problems • improves productivity •	• time consuming • it does not show by how much the rejected products are defective	Supply-chain network, manufacturing company
Failure Modes and Effect Analysis (FMEA)	step-by-step approach for identification of possible failures	• a very structured and reliable method • the concept and application are very easy to learn	• is tedious and time consuming • not suitable for multiple features	Supply-chain network, manufacturing company
Plan-Do-Check-Act(PDCA)	an iterative improvement process and is run in repeating cycles	• can be widely applied • iterative process allows continuous delivery of improvements while moving towards the end goal	• does not give specific details about how to analyse/resolve problem • waiting time of 1st iteration is needed to address the impact of a problem	Supply-chain network, manufacturing company
Poka Yoke	Mistake proofing methodology	• error prevention • solutions can be implemented at low cost	• requires knowledge of utilizing instrumentation and technology	Supply-chain network, manufacturing company
5 S	Workplace organization method	• productivity increase • product quality increase	• misunderstanding of what 5S accomplishes • lack of management support	Supply-chain network, manufacturing company

Management in an average production-oriented company has a tendency to set highly positioned quality goals that should be based on efficient manufacturing processes. Despite the fact that quality tools (Table 1) and methods (Table 2) are not presenting any novelty in manufacturing industry, a proper and detailed root-cause analysis of a problem has to be made in order to choose a corresponding quality tool and/or method that leads to a company's performance improvement.

The reviewed literature states that manufacturing-industry practice is optimizing its internal processes by the application of FMEA, PDCA and Poka-Yoke, while product quality is many times optimised by the application of QFD and Cause-and-Effect diagrams [7]. The benefits of QFD and PDCA are presented in the following paragraphs.

The applicability of a PDCA methodology in manufacturing processes

The classic PDCA method includes four elements of process control: planning (preparation of the quality-assurance plan), execution (integration of improvement measures), checking (control of effects) and action (implementation of measures according to the determined deviations in the control of effects) [10, 22]. The classic PDCA method excludes performance monitoring to ensure the on-going effectiveness of change. Andersen *et al.* [11] state that the users of the classic PDCA method are not experienced enough to use it in an effective way, and therefore they propose an improved type of PDCA method, which includes the elements shown in Fig. 3: characterization and research into the problem, analysing the situation, preparation of measures to improve, a critical assessment of the reasonableness of the measures, implementation of the measures, and checking the effects of the implemented measures for improvement.

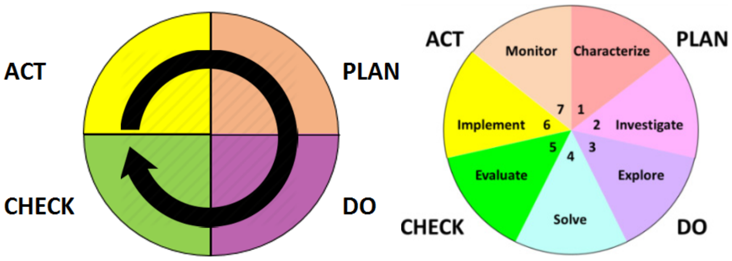

Fig. 3 Classic PDCA method (left) vs. improved PDCA method (right) [10, 11]

In order to prove the efficiency of both the classic and improved PDCA methods one typical automotive supplier manufacturing company was chosen as the unit of analysis. The company faced an increased rate of scrapped products on one of its biggest assembly lines, where counter measures to increase product quality represented a top priority. The management of the company defined a 4-weeks time frame to resolve quality issues and gave approval for the parallel application of both PDCA methods. The initial scrap rate was 320 products with unacceptable quality, while the target scrap rate, defined by the management, was 40 products with unacceptable quality.

After the 4 weeks of parallel testing was over, the results were analysed and are presented in table 3. The use of the classic PDCA method resulted in a 44 % decrease of products with unacceptable quality, while the improved PDCA method eliminated products with unacceptable quality.

A reduction* of 100 % is achieved by using the error prevention Poka-Yoke method, proposed by the improved PDCA method. However, we cannot generalize the statement that the use of the improved PDCA method will always eliminate products with unacceptable quality. Based on a parallel comparison of PDCA methods, shown above, the same procedure could be applied for other quality tools and methods.

Table 3 Analysis of parallel application

	Classic PDCA method	Improved PDCA method
Needed time for implementation	low	high
Implementation complexity	low	high
Level of structured approach	unstructured	structured
Problem-solving mind-set alteration	low	high
Problem-solving efficiency	low	high
Scrap reduction*	44 %	100 %

The applicability of the QFD methodology in manufacturing processes

The question is, what goals does a company envisage to satisfy or merely please its customers? The answer to this question is the QFD method, which represents a quality system focused on the customer (Fig. 4). The method initially identifies the customers' needs and expectations, and then defines the correct responses to them. QFD is a method enabling companies to achieve the optimal satisfaction of its customers [17].

Quality	→	implement customer requirements
Function	→	what specifically needs to be done
Deployment	→	who will do it and when

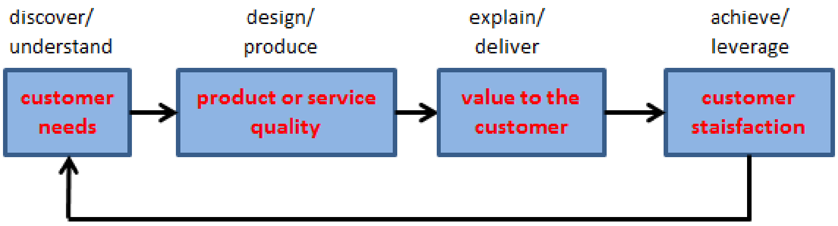

Fig. 4 Process display of the QFD method [35]

The QFD method represents a process that allows the identification of customer requirements, understanding markets and knowledge of different customer segments. The conditions for the successful implementation of the QFD method are a thorough knowledge of the requirements of each customer segment, how important the customer's benefit is and how effectively these requirements are met by existing suppliers of products/services [23, 35]. If these conditions are not met, the customer requirements are obviously unknown and, consequently, products/services cannot be consistently delivered to the market and would prevent customers from being generally satisfied [36]. The QFD method is therefore a quality-assurance system with the aim of maximizing the customer's satisfaction. It focuses on providing value in a product that delivers both spoken and unspoken customer requirements or expectations. These requirements are translated into the (development and production) activities of the producer. The QFD method allows cross-referencing of the product's producer with its competition by helping the company to direct further steps in the direction that will help increase competitive advantage [23, 34].

3.3 Influence of the quality of the manufacturing processes on manufacturing cost efficiency

The purpose of this section is to highlight the connection between the high-quality manufacturing processes and the cost efficiency of the manufacturing process. Companies are aiming to develop high-quality manufacturing processes, which are in turn enabling higher profits for the company. For that reason there is a need to reliably assess the manufacturing cost efficiency. There are various authors expressing different innovative approaches related to the measurement and improvement of process efficiency. According to Hendricks *et al.* [32], product quality is crucial to the success of any company – as evidenced by the statement that the companies that are winning awards for outstanding quality, achieve higher profits and a higher value of their shares on the stock market.

Process control is very important for improving the efficiency of production processes. Each serial production is designed in such a way that it can be effectively monitored, which can be done through constant control of important parameters, whereby it is necessary to effectively respond to any perceived deviation from the nominal value. The efficiency of the manufacturing processes is closely associated with productivity processes – it is important to ensure a continuous production process with or without the shortest-possible standstill and with zero or minimum poor-quality products [24]. Hanenkamp [25] describes a method for the control of production processes, described as "*Overall Equipment Efficiency*" (OEE), which uses the relative value to define the level of availability of machinery and equipment, quantity and the degree of product quality, with Eq. 1:

$$OEE = availabilaty \times performance \times quality \tag{1}$$

The *availability* rate is the ratio between the available working time of the machinery and equipment and their actual working time; the *productivity* rate is the ratio between the available working time of the employees and their actual working time; the *quality* level is the ratio of the quantity of poor-quality products and the total quantity of manufactured products.

Involving employees in a process-performance measurement (OEE, productivity, etc.) is very important. The productivity of companies is affected by the use of the 5S method, described as a method for organizing and standardizing workplaces within the company. An appropriately structured workplace motivates employees, both production workers and management, improves occupational safety, the productivity of the process and evokes a sense of responsibility among the employees [24-28].

Several authors [25, 28-30] also mention the Shop Floor Management method (SFM), the main advantage of which is a systematic, process-oriented industrial way of solving problems. The SFM method pursues three objectives: *gemba* (real venue, for example, assembly line), *genbutsu* (detailed knowledge of the affected process, e.g., increased scrap) and *genjitsu* (definition and implementation of corrective actions that will improve the current issue). Tanco *et al*. [31] propose a methodology to measure the impact of SFM on defect-free production, which can be summarised in the following steps: a) choose an adequate response (the impact of SFM should be measured in different ways: firstly, as the impact on defect-free cars and then in the last quality-control stage), b) gather significant data (to carry out a relevant statistical analysis, a significant amount of data must be gathered to give certainty to results), c) analyse several factors (production level, week day, shifts, quality level), d) draw conclusions and recommendations.

Jingshan *et al*. [33] speak about the certain demise of a company, if the company is only partially focused on improving the level of quality. They point out that product quality is not just vital for the profitability of the company, but also for its existence. Manufacturers want to cooperate with fewer suppliers, but the latter need to be large and strong enough for all the customer's requirements. This is due to the fact that the typical construction of products requires a large number of components; therefore, it makes sense that as many components as possible are supplied by one or a few suppliers. There is a risk that the parts purchased from a large number of suppliers would not be compatible [17]. Production-oriented companies implement operational processes by attempting to minimize resource consumption, in addition to realizing planned quantities of products that meet customer requirements regarding quality [36].

Hanenkamp [25] emphasizes the importance of using the SFM method in manufacturing processes, which results in improved productivity, a reduced rate of customer complaints and higher profitability of the company.

Manufacturing efficiency is of huge importance within every company. It is important to ensure a continuous manufacturing process with the shortest possible standstill and with the minimum number of poor-quality products. Therefore, manufacturing processes are cost efficient only if there is a reliable performance measurement integrated (established by SFM method) and if the mind-set of the employees is accepting the importance of quality (quality methods and tools). Fig. 5 illustrates major contributors to the improved cost efficiency of manufacturing processes, where the value of each contributor is assessed based on the available literature [24, 25, 28-30, 32, 33, 36].

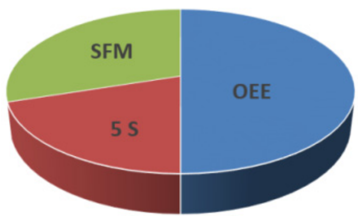

Fig. 5 Major contributors to cost efficiency [24, 25, 28-30, 32, 33, 36]

4. Discussion

The future of component suppliers will be financially successful only if they reduce the cost of doing business and start to produce products that can be sold to different customers, even beyond their core sector. Productivity and scrap levels impact on the operating costs, notes Hanenkamp [25], who recommends the use of methodologies for measuring the OEE. From the manufacturer's point of view the measurement of productivity and OEE is important because it exposes process deviations in real time and enables opportunities for process improvements.

Based on a literature review we see that not all quality methods and tools can be equally implemented in all company departments. The classification of quality methods and tools into different manufacturing departments is divided into three main pillars, seen Table 4. We identified the prime responsibility and initiatives for a particular pillar in terms of quality deployment.

Table 4 A proposal for quality methods and tools deployment within company departments

Quality dpt.		Pillars		
		Research and Development dept.	**Production dept.**	**Customer support and service dept.**
Quality methods	QFD	yes	no	no
	SPC	no	yes	yes
	FMEA	yes	yes	yes
	PDCA	no	yes	yes
	Poka-Yoke	no	yes	no
	5 S	no	yes	no
Quality tools	Cause and effect diagram	no	no	yes
	Flow chart	yes	yes	yes
	Control table	yes	yes	yes
	Control chart	no	yes	yes
	Histogram	no	yes	yes
	Pareto diagram	yes	yes	yes
	Scatter plot	yes	yes	yes

In Table 4, a horizontal line indicates a quality department that represents cross cutting through all three pillars: the research and development department, the production department and customer support and service department.

From the manufacturing point of view and based on manufacturing experiences we present some examples where the application of certain quality techniques (combination of tools and methods, presented in Table 3) can be implemented:

- unacceptable low level of first pass yield within the manufacturing process is increased by the application of SPC, FMEA, Cause-and-effect diagram and Histogram,
- increased number of scrapped components within the manufacturing process is usually decreased by the application of PDCA, 5 S, Control Table and Pareto diagram,
- a large number of customer claims related to the technical properties of the product are solved by the application of QFD, FMEA, Histogram and Pareto diagram.

Also other combinations/techniques of quality methods and tools are possible, depending on the manufacturing processes. Generic flowchart, presented in Fig. 6, introduces correlations between KPIs and quality techniques, whose application would resolve the deviations of the KPI.

Based on manufacturing practice we are able to identify that the increased scrap rate, caused by poor product design, is resulting in a lower product yield and a lower OEE of production line, while the increased scrap rate, caused by poor process design, is again resulting equally in a lower OEE of production line. The correlation between product and process improvement is therefore mutual, as the improvement of the product will directly improve processes and vice versa.

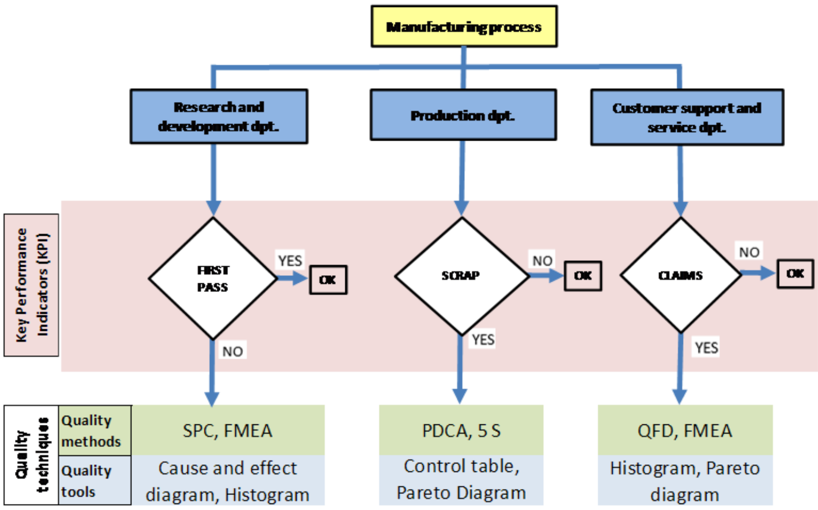

Fig. 6 Application techniques of quality methods and tools

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The increased complexity of the manufacturing processes is demanding an effective approach to resolve issues that are connected to poor quality in manufacturing. For that reason the following questions arise:

- How do we identify critical production processes and which methods should we use to improve OEE?
- How do we inspire employees in the company to adopt new quality methods and tools to improve the manufacturing efficiency?
- How do we use the QFD and new PDCA methods to fulfil the customer's expectations, assuming that mass production of the product is already in progress?

Although the most critical manufacturing processes can be detected using the SPC method and control chart tool, we are of the opinion that the application of the SFM method delivers better results through the identification and implementation of corrective actions that will improve the current issue, which will result in improved OEE. In addition, the SFM method motivates employees and their leaders through its systematic approach, where quality techniques need to be applied to every single quality issue.

Based on manufacturing experiences, where customer satisfaction with a product always plays a big role in a company, we propose the use of the QFD method, which successfully translates customer requirements into product specification. During the mass production of those products there are various manufacturing issues, related to the quality of the product, which can be solved by the use of the new PDCA method.

5. Conclusion

In today's highly competitive environment supplier quality is a very important operational issue for a modern, successful, and profitable production system. Confidence in a supplier's ability to deliver a component as part of the final product that will fulfil customer's needs can be achievable through the efficient quality traceability from the manufacturer to the suppliers.

This paper initially describes quality challenges within manufacturing processes, which is achieved through the integration of the quality tool and methods. The strengths and weaknesses of various quality methods and tools are revealed and potential applications in manufacturing fields are presented. The parallel application of two quality methods on a manufacturing process was performed, while the positive effect of the usage is proved with a decrease of 44 % (first method) and 100 % (second method) of products with unacceptable quality.

The concepts of high OEE and high manufacturing quality are shown to be very important to secure a positive financial future for the company. Therefore, this article as a review of common quality tools and methods serves as an incentive for the definition of a new approach to the improvement of OEE, the reduction in the rate of complaints and the procedures for a faster and more efficient response to deviations within production processes.

Based on a general manufacturing model we propose a generic flow chart that identifies quality techniques for a particular KPI within the manufacturing process. Manufacturing processes are cost efficient only if there is a reliable performance measurement integrated and if the mindset of employees is willing to accept the importance of quality; therefore, we can also conclude that the use of methods and tools (QFD, 5 S, PDCA and SFM) significantly improves the efficiency of the processes.

This paper should serve as a basis for carrying out detailed analyses of manufacturing processes before and after the implementation of the above-described quality techniques. Consequently, manufacturing managers could motivate their staff to implement the above-described quality-assessment techniques more effectively.

Acknowledgment

We sincerely thank the reviewers of this journal for their insightful comments which helped us improve the quality of this paper. Authors are expressing their gratitude to Faculty of Electrical Engineering, Laboratory of Metrology and Quality for their financial support.

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