Application of Innovative Quality Control Methods in the Manufacturing Process of Components for Automotive Industry

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Abstract

From today's perspective, it is increasingly important for component manufacturers to set up and manage their production processes correctly, including monitoring and verifying the final product quality. The basic requirement is to produce parts efficiently while maintaining the required manufacturing tolerances and final product properties while respecting the specifics and limitations of the chosen manufacturing technology. This is particularly true in the automotive industry, where increasing demands for precision and a high level of quality can be observed, driven by specific industry requirements. This paper aims to show innovative approaches for the prevention of quality problems in the production of cast components for the automotive industry. Innovative quality management methods and tools will be presented, and their possible applications will be explained. Furthermore, the possibilities of applying virtual and augmented reality and other modern tools within Industry 4.0 to achieve more efficient production and the desired quality of final products will be discussed.

Keywords: manufacturing technology, automotive industry, product quality, Industry 4.0

JEL Classification: L91, M11, Q55

1. Introduction

In a competitive environment, as we know it nowadays, a focus on high quality and product quality in general is a key prerequisite for competitiveness in all sectors, whether manufacturing or non-manufacturing. Hence there is a need to introduce and implement quality management systems in organizations. In addition, the industrial sector is undergoing a period of change in the form of digitalization, the introduction of autonomous systems, and the drive to connect all business activities in the context of Industry 4.0. This is linked to the adjustment and adaptation of other related processes such as Logistics 4.0 (Menti, 2023) and Quality 4.0 (Jokovic, 2023). The implementation of innovations (Kovács, 2023) is also an important and long-term trend these days, in all sectors (Alarcón-Martínez, 2023). The automotive industry is a sector where all these trends are applied, and it can be said that this sector is one of the most dynamic. This is matched by the high demands on the quality of the final product and the need to implement quality management systems in organizations. In addition to the standard requirements, the automotive industry is characterized by increased demands for the application of modern quality management tools and methods such as FMEA (Failure Mode and Effects Analysis), C-E diagram (also known as Ishikawa diagram), control and management plan, etc. Further, the required and quite commonly used approaches in automotive quality management include PPAP (Production Part Approval Process), which is an integral part of the product approval process in mass production (Folta, 2015). The 8D report is also a used and very beneficial approach for solving quality problems in the automotive industry (Barsalou, 2023). Furthermore, it is important to apply the principles of continuous quality improvement in the automotive industry, for example using the DMAIC method within Six Sigma (Sumasto, 2023), (Knop, 2023). As far as the production of automotive parts, each production area is mainly defined by the type of material used and the production technology utilized. Thus, the final shape of the product and the level of manufacturing tolerances should be designed concerning the material and manufacturing technology. This also applies to the production of castings for the automotive industry, which are produced in metallurgical plants (foundries). These are specific and energy-intensive production plants. Therefore, innovations and various process optimizations (Scharf, 2021) are needed here, in line with the principles of lean manufacturing (Saetta, 2020). Related to this is the high importance of implementing modern quality management methods and tools. In the following part of this paper, selected quality management methods and tools will first be presented in detail and then applied to the example of a company producing castings for the automotive industry. Furthermore, new trends in the automotive industry quality management will be mentioned.

2. Quality control methods and tools in the automotive industry

To improve any system using a systematic approach, there is a need to understand the processes using the knowledge of simple quality tools and techniques. The effective use of these quality tools and techniques similarly requires that they must be applied by people who have a good understanding of the ways they are used or applied to achieve quality products and services; hence, there is a need to train all those involved in their use and application adequately. The support and commitment of management in the provision of adequate training is hence of immense importance to organizational survival. The main impact of using these quality tools and techniques is on a general basis for the overall improvement of the products and services by improving processes and operational tasks. They help in the understanding and provision of problem solutions hence their use and application for the understanding of problems and providing solutions for the improvement of quality. Various quality tools have emerged over the years, some of them are numerically based while others are not (Ibidapo, 2022).

2.1 8D Report

Each organization has its process for managing product quality issues. 8D report is considered one approach to problem-solving and is widely used in the automotive industry. The 8D problem-solving approach was invented by the American Ford Motor Company in the mid-1980s and has also been updated several times. And it was the latest update that added the ninth step, D0. This approach is essentially designed to eliminate defects so that they don't happen again in the future. The steps are labelled D0– D8. The letter D is from the word discipline and the numbers indicate the steps in the process. The steps of the 8D approach consist of (Stamatis, 2016):

- D0: Preparing for the 8D process and establishing the needs for starting the 8D method.
- D1: Creating a small team where the workers in the group will have the necessary knowledge of the process, the appropriate skills, and the authority. In addition, one team leader will also be identified.
- D2: Customer problem description. The more precise the problem definition, the better the chances of a successful solution.
- D3: Creation of an interim corrective action. An interim corrective action must be created so that the customer's problem does not persist until long-term measures are deployed.
- D4: Diagnosis of the problem. At this point, the root cause of the problem must be discovered and defined.
- D5: Establish a permanent corrective action to address and contain the problem and then verify the absence of adverse effects.
- D6: Implement the corrective actions and monitor the effectiveness and results after the actions have been implemented.
- D7: Modify the necessary systems to prevent the problem in the future.
- D8: Highlighting the team and individual work of the assembled team members.

It is advisable to check and verify the process once it is completed. It is clear from D0-D8 that these are basic but very effective measures that often lead to the elimination of the problem (Stamatis, 2016).

The 8D approach is also associated with many practical tools and methods used not only in the automotive industry. Some of these main quality tools and techniques are described below.

2.2 Cause and Effect Diagram (C-E Diagram)

The cause-and-effect diagram, commonly known as the fishbone or Ishikawa diagram, serves as a tool for brainstorming and analysing the underlying causes of quality management issues. Developed by Ishikawa, this method facilitates the examination of factors contributing to a specific outcome, establishing connections between causal factors and quality effects. By systematically organizing potential causes, the cause-and-effect diagram aids in identifying the root causes of a given effect in a logical manner.

The process of creating a C-E diagram can be defined by the following steps (Malindzakova, 2019):

- clear definition of the problem,
- defining the main groups influencing the problem,

- identifying the causes of the problem, which will be divided into the main groups of the diagram,
- analysis of the diagram and causes.

The C-E diagram is divided into main groups, organized according to Ishikawa's principle of sequence and continuity of the process in time: Materials, Methods, Technologies, Measurements, Men, and Environment. C-E diagnostics is the basis for the creation of FMEA (Malindzakova, 2019).

2.3 Failure Mode and Effect Analysis (FMEA)

FMEA is an extremely popular technique in improving product and process reliability by analysing defects before they occur and taking preventive actions before possible causes of defects (Stamatis, 2016). The main benefits of this method include (Nenadál, 2018):

- a systematic approach to prevent poor quality,
- prioritization of actions based on quantification of the risk of potential defects,
- design optimization leading to a reduction in the number of changes in the implementation phase,
- creating a valuable information database on the product or process,
- minimal implementation costs compared to the costs that could be incurred if defects occur.

The implementation of FMEA depends on a multidisciplinary team of experts, usually consisting of process engineers, technicians, quality engineers, and design engineers. For the team to work effectively, a facilitator is appropriate (Maisano, 2020). Each FMEA is divided into four stages (Nenadál, 2018):

1. Analysis of the current situation.
2. Assessment of the current situation.
3. Proposal of preventive measures.
4. Assessment of the situation after implementation of the preventive measures.

It is currently one of the most sophisticated risk management methods used in the process of product and process quality planning and improvement.

2.4 5Why method

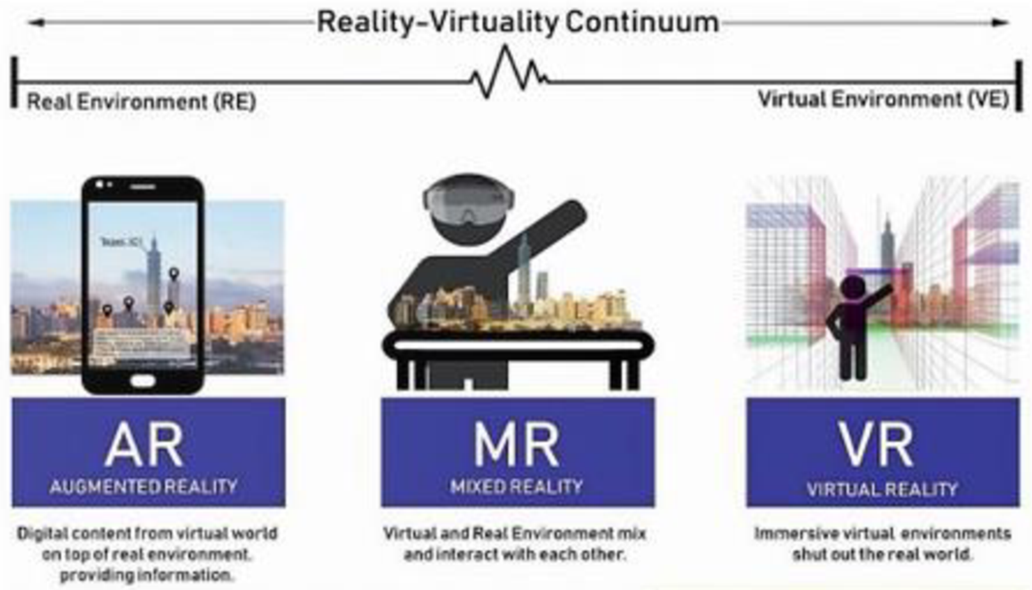
The 5Why method is an in-depth root cause investigation technique that is often used in quality management and process improvement. The principle of this method is to repeatedly ask "Why?" questions to identify the hidden or deeper causes of a given problem. When a specific problem is identified, the team or person asks, "Why did this happen?" and then continues asking "Why?" questions until the root cause of the problem is reached. Typically, five iterations are used because experience shows that, on average, the root cause of the problem is revealed after the fifth question. However, the number of questions may not be fixed and may vary depending on the complexity of the problem and situation. The aim is to uncover the real factors that led to the problem so that effective measures can be put in place to prevent its recurrence. The 5Why method is not just a tool for identifying the surface causes of problems but rather serves to uncover deeper causes that might otherwise remain hidden. This enables effective problem-solving and strengthens continuous process improvement in the organization.

2.5 New trends in automotive quality control

The literature shows that in most cases Quality 4.0 is seen as a subset of Industry 4.0. For example, Jacob (2017) and some other authors simply see Quality 4.0 as the integration of "new technologies with traditional quality methods to achieving new optimums of performance, operational excellence, and innovation".

The wave of digital transformation embodied by Industry 4.0 has brought the industry into an era where the fusion of physical and digital systems is not only likely but essential to increasing operational efficiency. The centre of this fusion is virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies, each with distinct capabilities and applications. To better understand the basic differences between the three technologies, see Figure 1 (Osorto, 2021). On one hand, VR immerses the user in a completely digital environment and separates them from the physical realm. On the other hand, AR maintains a connection to the physical world but overlays it with digital content, allowing a moderate level of interaction with digital overlays. MR belongs between these two extremes and embodies the strengths of both, creating a realm where digital and physical entities interact in real-time (Ibidapo, 2022).

Figure 1: Differences between AR, VR, and MR



Source: (Ibidapo, 2022)

Quality control is one of the many applications where MR can be used effectively. MR devices alert workers to critical points and guide them through the inspection process while recording the steps taken and the findings. This form of inspection can be used at any stage of the manufacturing process and the collected data are stored, interpreted, and can be used to generate inspection reports.

Despite the promising prospects, several obstacles hinder the widespread adoption of MR in the industry. One of the main problems is the high cost of implementation. Acquiring modern hardware, software and the necessary infrastructure for MR can be costly, especially for small and medium-sized companies.

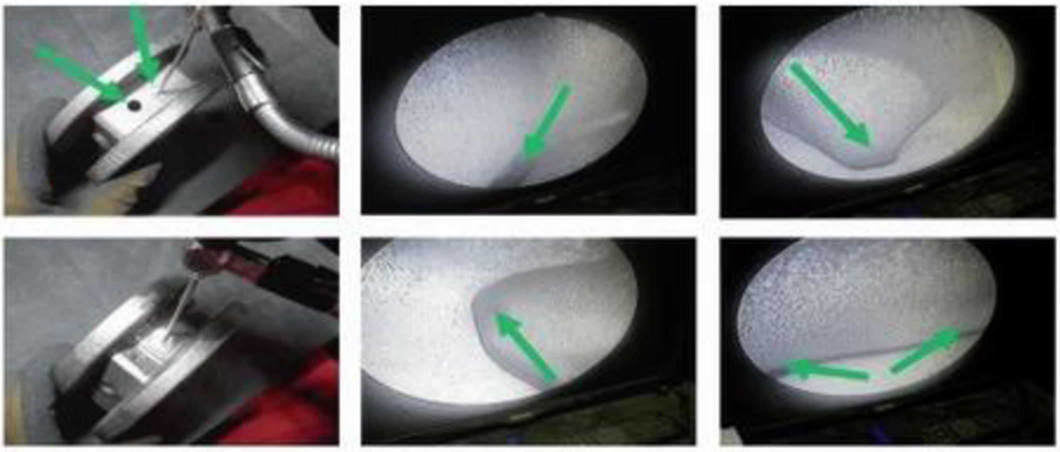
Technical constraints also pose significant challenges. Accuracy and reliability of MR systems are paramount and any inconsistency in the real world like tracking or digital overlay can lead to wrong decisions and operations. In addition, latency issues can negatively impact real-time interactions, a critical requirement for many industrial MR applications.

Augmented, virtual and mixed reality tools can be practically used in the automotive industry in various areas of operation, such as warehouse picking, assembly processes, hands-free logistic processes, quality control (product audits), tool changes, maintenance, and repairs.

3. Practical application of quality management methods in a selected manufacturer of castings for the automotive industry - Case study

The quality control management tools and methods described in the previous chapter were applied to an organization producing foundry products. This company produces, among other products, mainly grey cast iron parts that are used after machining in the assembly process of turbochargers in the automotive industry. Turbochargers are often used, especially in high-performance engines and in the pursuit of better vehicle economics. It is therefore clear that the technical requirements for the quality of all parts (meaning turbocharger parts) and their compliance during the manufacturing process are essential. These are defined by the engine manufacturers in the automotive industry in the relevant technical specifications (drawings, standards, simulations, etc.). While monitoring the production process, the company observed a relatively high incidence of parts that had a problem with the water passage in the turbocharger body. The same problem was also identified in one of the parts the company received from a customer who subsequently machined the cast parts for the final assembly of the turbocharger. Subsequently, analyses of the claimed parts were carried out using a boroscope and the water channel obstruction was confirmed (see Figure 2 - indicated by green arrows).

Figure 2: Turbocharger body with an impassable water channel after boroscope analysis



It was then necessary to find out the causes of the main problem in the form of water passage in the turbocharger body. Therefore, further analyses were carried out. Using X-ray inspection and analysis of the parts in the section, the problem of residual sand inside the water channel was identified (see Figure 3).

Figure 3: Residual sand inside the water channel after X-ray analysis and in the real turbocharger body section

As part of the structured problem solving (using the 8D report) it was important to find the cause(s) of the residual sand in the water channel. To fulfil this aim, a multifunctional team was created consisting of personnel from different/relevant departments (e.g. engineering, quality, technology, production). This team defined the probable causes of the problem using the C-E diagram. The outputs from the diagram are summarised in Table 1.

Table 1: Root causes outputs from C-E diagram

MAN	**METHOD**	**ENVIRONMENT**
Poor positioning of the part	Work instruction for shot blasting is not properly defined (how to control the water channel if the circuit is blocked)	Too small workplace for the operator
During shot blasting skip part operation	Too short time for shot blasting	Poor lighting
Not performed vibrating operation		
	Not enough of shot blasting media	
	Damaged shot blasting pipe	
	Too low pressure of compressed air during shot blasting	
	Blocked shot blasting nozzle	
MEASUREMENT	**MACHINE**	**MATERIAL**

Of all the probable causes listed in Table 1, the team agreed that those marked in green were the most important. These are:

- vibrating operation was not performed – the root cause of the defect,
- work instruction for internal shot blasting was not properly defined (how to control the water channel during shot blasting if the circuit is blocked) – the root cause of the non-detection.

Based on knowledge of the root causes for the defect itself and non-detection the corrective actions were defined first and implemented afterwards. Those were:

- installation of a robot for automatic feeding into the vibrating machine.
- additional quality control during inside shot blasting of water channel if the circuit is blocked.

The team took an FMEA method focused on the casting vibration process. The aim was to confirm that this production step is very important for the quality of the final product. The FMEA analysis showed that the quality control of the water channel permeability by the boroscope is insufficient and therefore very risky for the manufacturer (see RPN=448). All information can be seen in Table 2.

Table 2: FMEA method focused on the casting vibration process step

Process step	Vibration (castings)
Potential Failure Mode	Omitted operation of vibration
Potential Effect of Failure	Sand residues inside the water channel
S (Severity)	7
Potential Cause	The operator missed a product
O (Occurrence)	8
Current Control	Quality control by boroscope
D (Detection)	8
RPN (Risk Priority Number)	448
Actions for improvement	Installation of a robot for automatic feeding into a vibrating machine

After the successful installation of the automatic feeding robot in the vibrating machine, the risk of water channel clogging has been reduced based on the re-calculation of RPN.

4. Conclusion

As far as we know, this is the first paper that analyses the impact of European emission standards on the value of European car manufacturers in the stock market and the paper leads to a clear result. Stricter emission standards have negative effect on the value of car manufacturers in the stock market. Comparing the year over year performance of car manufacturers shares to the stock indices, it is apparent that since the emission standard Euro 6 was introduced, the stocks of car manufacturers perform worse than the indices that they are part of even though they did better until the introduction of the Euro 6 emission standard.

This paper can therefore be used as a proof that the tightening of emission standards in automotive must corelate with the technological advancement if the regulation wants to be successful. Once the tightening of emission standards is too quick, many car manufacturers might get into problem and as automotive industry is very important in Europe, this might bring serious problems. Looking at the development of the share price of selected car manufacturers and their comparison with stock indices, it can be argued that even investors in the stock markets are aware of the difficulties that the Euro 6 emission standard brings with it.

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