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QUANTITATIVE ANALYSIS OF NONCONFORMING PRODUCTS: A CASE STUDY IN THE AUTOMOTIVE INDUSTRY

ABSTRACT: This paper presents an analysis of nonconforming products within a case study conducted in an automotive industry company. Utilizing monthly data over one year, the study examines trends in nonconformance and associated costs. Descriptive statistics reveal significant monthly variations in nonconforming products, while correlation analysis indicates a strong relationship between the frequency of nonconforming products and the incurred costs. The findings suggest that addressing the most frequent types of nonconforming products could lead to substantial cost reductions. Key recommendations include implementing targeted preventive measures, such as enhancing employee training, adhering to operational procedures, and optimizing machinery and equipment settings. Establishing a robust quality control system is essential for minimizing nonconformance.

KEYWORDS: nonconforming products, automotive industry, costs, statistics

INTRODUCTION

One of the significant challenges faced by industrial enterprises is the occurrence of nonconforming products. The presence of nonconforming products can result in a lower output of conforming, or good and acceptable products, compared to what was planned in the production schedule. A nonconforming product is one that fails to meet the criteria for delivery to customers and, therefore, cannot be considered an acceptable outcome of the manufacturing process. Even if a company effectively plans and directs its production capacities according to forecasted demand, the occurrence of nonconforming products can significantly impact the execution of plans and the achievement of production goals.

Nonconformities in the manufacturing process occur when a process or product does not meet defined requirements (such as standards, customer requirements, or defined plans and goals) [10]. Generally, nonconformities can result in various consequences, including inadequate product quality, loss of customer trust, and negative impacts on the company's reputation. To effectively manage nonconformities, it is essential to establish procedures and mechanisms for their identification, analysis, and resolution.

In this study, the occurrence of nonconforming products was analysed using descriptive statistics, interval ratings, and correlation analysis. The aim of this paper is to identify and analyse the causes of nonconforming products, as well as to evaluate their impact on the effectiveness of the manufacturing process. The analysis was further enriched with graphical representations and examples of applying specific statistical functions in Microsoft Excel.

The case study presented in this paper is based on data from a company in the automotive industry. The company belongs to the category of small and medium-sized enterprises. Its product range consists of aluminium products

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processed on hydraulic presses. The company's primary product is radiator housings for electric vehicles, but its product range also includes other products obtained through similar processing methods. The company is certified according to the IATF 16949:2016 standard, which represents a quality management system tailored to the needs of the automotive industry.

TYPES OF NONCONFORMITIES IN THE MANUFACTURING PROCESS

In the manufacturing process, both major and minor nonconformities may arise. The difference between major and minor nonconformities is reflected in their consequences and the hierarchical level at which they occur [10].

Major nonconformities typically occur more frequently and can significantly impact productivity. They can directly lead to customer dissatisfaction and negatively affect the manufacturing process, resulting in increased costs, waste, and potential financial and other penalties for failing to meet specific standards. Minor nonconformities, on the other hand, are not as frequent and, even when they occur, can generally be easily detected and quickly resolved by production workers [10].

Major nonconformities may include issues such as [16]: documentation problems, lack of management control, an absence of internal audits, inadequate employee training, and lack of customer feedback monitoring. These are systemic nonconformities that, starting from top management, affect all business processes, including the manufacturing process.

Examples of minor nonconformities in an industrial setting might include missing training records or invoicing errors, while in the manufacturing process, minor nonconformities might manifest as unnoticed nonconforming products or improperly calibrated devices. If a minor nonconformity recurs too frequently, it is then considered a major nonconformity. For example, if a nonconforming product is not identified and removed over a long period, it is treated as a minor nonconformity. Conversely, if this issue happens daily, it indicates a more serious problem and is regarded as a major nonconformity [16].

This paper focuses on nonconforming products. It is considered essential for every company to establish and regularly update procedures for product control to ensure that products meet defined requirements. Nonconformity of products can result from defects arising in the manufacturing process, non-compliance with standard requirements, and issues with material supply. Additionally, product nonconformity may involve physical damage, dimensional irregularities, non-compliance with technical specifications, or lack of functionality. Such products do not meet the expected standards and are unacceptable to customers.

Product nonconformity can negatively impact a company's reputation and may lead to customer loss or, at best, merely result in fines. Therefore, it is crucial to identify and address nonconformities promptly to ensure product quality and customer satisfaction. Implementing appropriate control measures and procedures can help reduce the number of nonconformities and enhance manufacturing process efficiency.

Establishing a procedure for managing nonconforming products is crucial for both the manufacturing process and overall business operations. This procedure allows for effective and prompt responses to nonconformities in the manufacturing process and prevents them from reaching end customers. The process for handling nonconforming products is illustrated in Figure 1.

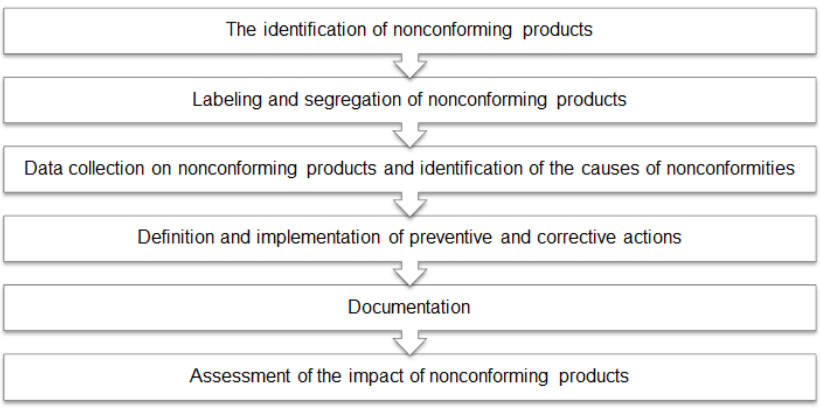

Figure 1 Procedure for managing nonconforming products [13]

When nonconforming products are identified, it is necessary to implement a system for labelling and segregating these products to prevent their mixing with conforming (correct) products. The labelling of nonconforming products should be clear and visible to avoid any confusion. The collection of data on nonconforming products involves gathering and documenting information about the nonconformities, including details about the product, the time and place of detection, as well as other relevant information. This data is essential for the successful identification of the causes of nonconformities and the implementation of preventive and corrective actions. In the end, all relevant information about nonconformities, identified causes, and applied measures should be properly and thoroughly documented. This allows for monitoring improvements, evaluating the effectiveness of the implemented measures, and assessing the damage potentially caused by the nonconformities [13].

OVERVIEW OF NONCONFORMANCE MANAGEMENT PRACTICES

The issue of nonconforming products has been extensively discussed in the relevant literature. Authors have approached this problem from various perspectives. For instance, papers [1, 17] have focused on the identification and analysis of nonconforming products. Additionally, a very common issue addressed in the literature is the prevention and management of nonconforming products [2, 11]. To approach the analysis of nonconforming products, some authors believe that it is essential to apply a specific methodology for their classification [4, 5].

In the automotive industry, the problem of nonconforming products has been primarily examined from the perspective of applying methods and tools for quality improvement [3, 7, 12]. Some authors have looked at this problem through the analysis of quality control efficiency [15], while a number of authors have approached the issue by proposing quality improvement strategies in the automotive industry [6, 14].

In the context of addressing nonconforming products, one method that has proven to be highly useful is Failure Modes and Effects Analysis (FMEA). FMEA enables the systematic identification of potential nonconformities in the manufacturing process and the evaluation of their potential effects on product quality. This method helps prioritize nonconformities based on their severity, occurrence, and detectability, allowing for a focus on the most critical areas and the development of effective strategies to address them. In the automotive industry, FMEA is used to enhance the reliability and efficiency of manufacturing processes, significantly reducing the number of nonconforming products and improving overall customer satisfaction. Relevant literature includes studies where FMEA has been applied in the automotive industry to address nonconformity issues in the production process [8, 9].

CASE STUDY

The subject of analysis in this paper is a company whose production facility is located in the vicinity of Kragujevac. The company’s headquarters is actually in Italy, while the production facility in the Republic of Serbia was established in 2013. The examined company is a supplier in the automotive industry's supply chain. In the Republic of Serbia, the company currently employs 52 workers, of which 42 are production operators. Thus, based on size criteria, this company can be classified as a small to medium-sized enterprise. Additionally, based on connectivity criteria, the company is part of a global supply chain. The company engages in mass production and operates at a mechanized technological level. Due to the confidentiality of the data and information presented, the name of the company under consideration is not disclosed.

The company's product range consists of 25 types of parts, predominantly aluminium, which are further incorporated into various types and purposes of vehicles. The main product the company supplies to its customers is a radiator grille for electric vehicles. The standard dimensions of the grille are 1400×1200 mm. Most of the products are manufactured using hydraulic presses, with additional manual and machine processing. In its production facility, the company currently operates 8 hydraulic presses, each with a maximum pressing force of 500 tons.

The production process involves several different job positions:

- Team Leader
- Quality Controller
- Forklift Operator
- Press Operator
- Maintenance Operator
- Warehouse Operator
- Other Staff

Production in this company is carried out in two shifts. Typically, the first shift operates at full capacity, utilizing the production equipment to its maximum and engaging approximately 2/3 of the production workforce. The second shift usually operates at reduced capacity, but, if necessary and in accordance with customer requirements, job reorganization is frequently carried out.

Analysis of the Occurrence of Nonconforming Products

The first issue addressed in this case study is the impact of nonconforming products on the effectiveness of the production process. The company produces 25 different types of products. The Quality Manager maintains records of the number of nonconforming products on a monthly basis for each product type. Figure 2 shows the number of nonconforming products over a one-year period.

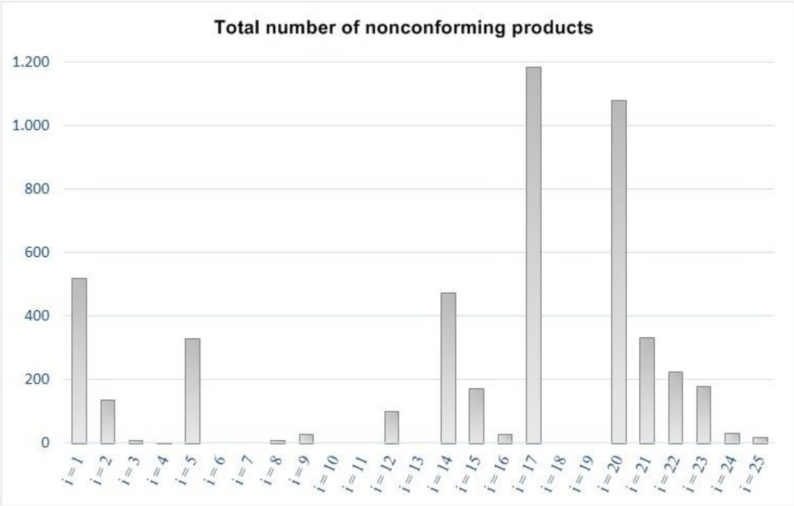

Figure 2 Number of nonconforming products on an annual basis for each product type considered (Source: internal company documentation)

Figure 2 shows that the highest number of nonconforming products is associated with product types $i = 17$ and $i = 20$. This information is particularly important for the Quality Manager. Analysing the presented data can provide insight into problematic segments of the production process. In other words, based on the displayed data, the Quality Manager can identify critical points in the manufacturing process. Subsequently, it becomes possible to identify the causes leading to the occurrence of nonconforming products, which could result in specific changes to the production process or modifications to quality control procedures.

The occurrence of nonconformities in these two product types is most commonly due to:

- Incorrect press adjustments,
- Improper material placement, and
- Inadequate initial quality control.

In this case, it is crucial to conduct regular and proper quality control, as well as to train operators to recognize and promptly report any irregularities in the product manufacturing process. Additionally, proper maintenance and adjustment of presses and auxiliary tools are essential.

For the Procurement and Logistics Manager, the number of nonconforming products on a monthly basis is also important, especially for the aforementioned two product types. The number of nonconforming products on a monthly basis for product types $i = 17$ and $i = 20$ is shown in Figure 3. The availability of this information is crucial for procuring raw materials and optimizing the logistics process. This enables the Logistics and Procurement Manager to manage inventory more efficiently, which further leads to a reduction in operational costs.

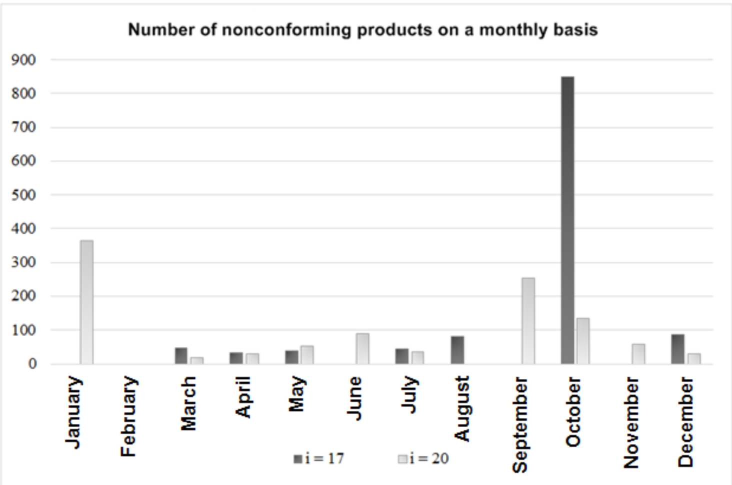

Figure 3 Number of nonconforming products $\mathrm{i} = 17$ and $\mathrm{i} = 20$ on a monthly basis (Source: internal company documentation)

Figure 3 shows a histogram of the quantity of nonconforming products $i = 17$ and $i = 20$ on a monthly basis. The highest number of nonconforming products for product type $i = 17$ occurs in January, while the highest number for product type $i = 20$ occurs in October. Based on these results, it can be concluded that organizing production was most demanding during these two months of the year under review. In other months, the impact of nonconformities of these two products on the effectiveness of the production process can be considered minimal. For example, issues with nonconforming products in the production process, aside from January and October, could have been easily resolved if there were safety stock of the necessary raw materials.

The number of nonconforming products primarily affects the effectiveness of the production process, which, in turn, impacts all business processes within the company. A high number of nonconforming products certainly leads to the inability to achieve set business goals.

Costs Arising from the Occurrence of Nonconforming Products

For the analysis of company operations, besides the quantity of nonconforming products, it is important to consider the costs incurred as a result of their occurrence. Figure 4 shows the costs associated with nonconforming products, specifically the costs directly related to the procurement of raw materials that remain unused as nonconforming products. These costs are expressed in euros and are presented for a period of one year.

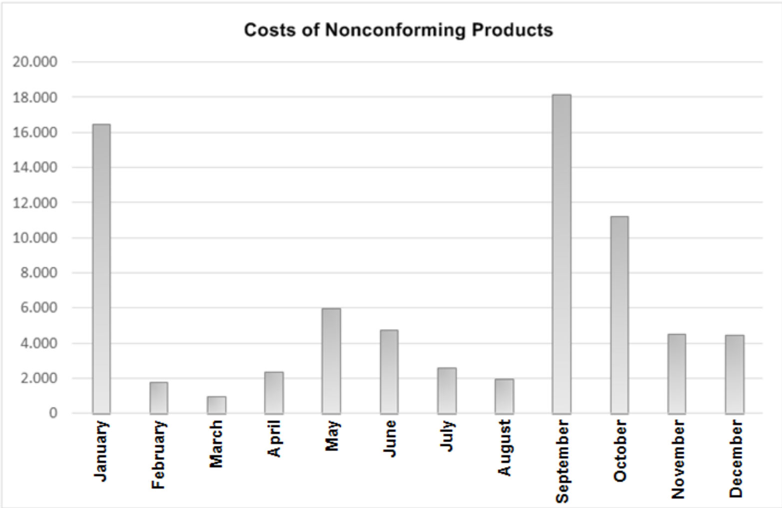

Figure 4 Costs Arising from the Occurrence of Nonconforming Products, Expressed in Euros

Figure 4 shows that the costs arising from the occurrence of nonconforming products are highest in September, January, and October. However, these costs should not be disregarded in other months. For the Finance and Administration Manager, this information is crucial as it directly impacts the overall business operations of the company.

Through further analysis of the costs of nonconforming products, their interval assessment has been determined. This analysis was performed using the descriptive statistics option within the Data Analysis package of Microsoft Excel, as shown in Figure 5.

Mean	6291,382423
Standard Error	1685,443922
Median	4510,46127
Standard Deviation	5838,549012
Sample Variance	34088654,56
Range	17208,65785
Minimum	991,04068
Maximum	18199,69853
Sum	75496,58907
Count	12
Confidence Level(95.0%)	3709,63706

Figure 5 Analysis of Costs Arising from the Occurrence of Nonconforming Products Using Descriptive Statistics (Data Analysis, Microsoft Excel)

From the analysis shown in Figure 5, the interval estimate for the costs arising from the occurrence of nonconforming products is:

$$6291{,}382 - 3709{,}637 \le \mu \le 6291{,}382 + 3709{,}637$$

$$2581{,}745 \le \mu \le 10001{,}019$$

Based on these results, it can be concluded that the expected value of the costs on a monthly basis may vary in the range from approximately 2500 to 10000 euros. In other words, these funds should be planned in advance and considered part of the financial plan.

Relationship between the Number of Nonconforming Products and Generated Costs

To improve product quality, the Quality Manager needs to take measures that will lead to a reduction in the number of nonconforming products. On the other hand, the implementation of these measures depends not only on the number of such products but also on the costs incurred due to their existence. To determine an appropriate set of measures, it is necessary to establish whether there is a correlation between the number of nonconforming products and the associated costs. In this study, the correlation was determined based on the correlation coefficient between these two variables (Tables 1 and 2).

Table 1 Quantity and Costs of Nonconforming Products at the Annual Level (Source: Internal Company Documentation)

i	Quantity	Costs (Euros)	i	Quantity	Costs (Euros)
$i = 1$	519	2711	$i = 14$	476	1571
$i = 2$	137	204	$i = 15$	173	501
$i = 3$	10	1	$i = 16$	29	87
$i = 4$	2	0	$i = 17$	1185	4235
$i = 5$	332	113	$i = 18$	0	0
$i = 6$	0	0	$i = 19$	0	0
$i = 7$	0	0	$i = 20$	1082	46425
$i = 8$	10	8	$i = 21$	334	11021
$i = 9$	30	7	$i = 22$	225	4051
$i = 10$	0	0	$i = 23$	179	2425
$i = 11$	0	0	$i = 24$	31	1397
$i = 12$	101	332	$i = 25$	20	404
$i = 13$	0	0			

Table 2 Correlation between Quantity and Costs of Nonconforming Products (Data Analysis, Microsoft Excel)

	Costs	*Nonconforming Products*
Costs	1	
Nonconforming Products	0.7	1

The correlation coefficient between these two variables is 0.7. This result indicates a strong correlation between the number of nonconforming products and the associated costs. As the correlation coefficient is positive, it can be concluded that products with a higher incidence of nonconformity also generate the highest costs. Therefore, it is essential to first address the measures for the products with the highest incidence, specifically products $i = 17$ and $i = 20$, for which the cost per nonconforming product is 3.57 and 42.9 euros, respectively.

In addition to the above, several other products also require special attention. The raw materials for products $i = 24$, $i = 25$, and $i = 21$ are relatively expensive, so preventing nonconformities in these products should be prioritized through appropriate control measures. Notably, product $i = 21$ has generated significant costs in the previous period.

Based on this analysis, the Quality Manager can optimize the resource usage necessary for addressing nonconformity issues. This optimization can be achieved by improving the quality control processes, organizing employee training, and implementing other preventive measures. Additionally, it is important to note that managing nonconforming products is a continuous process requiring the engagement of all business processes, from raw material procurement to production, quality, logistics, and sales.

CONCLUSIONS

In this study, an analysis of nonconforming products was conducted. Based on the records of nonconforming products, which were kept on a monthly basis over the course of a year, the trend of their occurrence was analysed. Additionally, an analysis of the costs arising from nonconforming products was performed. Correlation analysis revealed that the types of nonconforming products that occur most frequently also generate the highest costs. This indicates that implementing appropriate preventive measures to prevent these nonconformities would have a significant impact on reducing costs.

Some of the measures that should be undertaken to reduce the frequency of nonconforming products include adequate employee training, defining and strictly adhering to operational procedures, proper adjustment and preparation of machinery and equipment, and establishing a reliable quality control system. If any of these measures are not implemented or are not executed properly, nonconforming products will continue to occur.

To further enhance the effectiveness of the measures taken to address nonconforming products, it is crucial to establish a continuous improvement loop within the organization. This involves regularly reviewing and updating the preventive strategies based on feedback and new data. Engaging all relevant departments, such as procurement, production, quality control, logistics, and sales in this process ensures a holistic approach to problem-solving.

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