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Quality management support model in foundry enterprises

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Abstract

The state of the technical infrastructure determines the degree to which the quality requirements of products are met and has a significant impact on occupational safety. The purpose of this study is to build a universal model for supporting quality management, which allows the effective implementation of a wide-ranging research path supporting the evaluation of the relationship between the degree of modernity of product processing technology and the quality of the final product and the level of occupational safety. The developed model is verified by its implementation in one of the turning stations. A practical test of the quality management support model confirms that the practice of conducting analyzes of the level of modernity of infrastructure with its application contributed to identifying critical machine components, examining factors affecting the quality of technological operations, reducing uncertainty and the risk of risky events, and conducting activities in line with the concept of continuous improvement. The course of action detailed in the model makes it possible to determine the relationships that exist between key categories of factors and critical product defects, and accidents and near-misses. This allows for the proposal of adequate improvement measures. Further studies concern the implementation of the model at other workstations in the foundry company.

Introduction

Progressive economic changes have occurred as a result of the continuous increase in requirements for foundry products. Their properties and performance capabilities are aimed at the complete introduction of a market economy (Ismayilov et al., 2021; Malinowski, 2021). Thus, an economy within which there are markets influenced by internal factors (i.e., all factors relating to production, qualifications of personnel, and ways of managing the enterprise) and external factors (i.e., competition, market trends, and legal requirements) (Gawlik, 2016; Wu, Lin & Perng, 2022). As a result of market changes, business entities that actively participate in the market to ensure a stable position face the need to build and simultaneously implement competitive strategies (Holtzer, Dańko & Żymankowska-Kumon, 2012; Miskinis, 2021). Importantly, manufacturing companies participating in such turbulent conditions must efficiently use physical, financial, and human resources, while constantly tracking industry changes and conducting market research (Skotnicka-Zasadzień, 2010; Hys, 2015). The totality of changes taking place influences the need for constant evolution of the enterprise (Gries & Naudé, 2010; Kozłowski et al., 2019).

Using the technical infrastructure assets owned by an enterprise in an efficient manner is one of the key determinants of an organization's position vis-à-vis its competitors in the market (Hys & Hawrysz, 2012; Pacana & Czerwińska, 2019b). The indicated determinant has a fundamental impact on the effective execution of the production process, guaranteeing the expected level of quality of manufactured products and safety at the workplace (Ulewicz, Mazur & Novy, 2019; Wolniak, 2019; Bumba et al., 2023). Downtime resulting from machine and equipment failures has a negative impact on the stability of production processes and contributes to delays in order fulfillment. This is why it is especially important to implement corrective and preventive actions that effectively eliminate the root causes of problems (Klimecka-Tatar & Ingaldi, 2020; Ligarski, Rozalowski & Kalinowski, 2021).

Rational operation of technical infrastructure contributes to development success in the era of industrial progress (Pacana & Czerwińska, 2019a; Pietraszek, Radek & Goroshko, 2020). With such a background, the idea of activities called maintenance was formed (Silvestri et al., 2020; Siwiec & Pacana, 2021). The term maintenance is understood as a set of activities and processes closely related to production that is responsible for ensuring the correct operation and availability of a company's technical infrastructure (Wolniak, Szeptuch & Ziecina, 2017; Tran Anh, Dąbrowski & Skrzypek, 2018). Initially, maintenance was equated with activities to optimize the availability of machinery and equipment with relatively small inputs of a reactive nature (Pacana & Czerwińska, 2020). Nowadays, the maintenance function is seen as a complex and complicated process that involves both guaranteeing production efficiency and considering a risk-based thinking approach (i.e., the issue of ensuring the quality of the products offered and maintaining occupational safety) (Daryani et al., 2012; Zhang et al., 2022). The malfunctioning of technical infrastructure can be a threat to the company's employees and the environment (Mahapatra & Shenoy, 2022; Ulewicz, Czerwińska & Pacana, 2023).

Due to the continuous nature of the maintenance process, its management should be performed within the framework of an adequate operation strategy, which should be underpinned by meticulous analysis and audit of the actual needs and capabilities of the enterprise, as well as the requirements that arise from the specifics of the production process (Zhang et al., 2021). The maintenance process is often supported by IT and quality management tools. Various concepts are helpful during maintenance management, each focusing on selected important aspects (Agergaard et al., 2022). When used together – within a single system – they make it possible to create pertinent and complementary maintenance management concepts, e.g., total productive maintenance (TPM) and run to failure (RTF) (Kim, Lee & Kim, 2021; Singh & Gurtu, 2022; Pacana & Czerwińska, 2023).

However, it is crucial that both the tools supporting the maintenance process and the developed strategy are adequate to the actual state of the technological machinery park and the capabilities of the production enterprise. For this reason, the purpose of the study is to build a universal quality management support model, which allows the effective implementation of a wide-ranging research path to support the evaluation of the relationship between the degree of modernity of product processing technology and the quality of the final product and the level of occupational safety.

Method of study

The operation of manufacturing enterprises in a constantly changing environment is characterized by the continuous development of information technology, i.e., a strongly competitive industry, for which rapid changes in customer requirements require the implementation of improvement activities. The possibility of improvement in the field of quality management is the result of the availability of a considerable number of methods and concepts to support this process. In the context of ensuring a certain level of quality of manufactured products, a model is developed for managing the machining processes of aluminum castings. A diagram of the model is shown in Figure 1.

Step 1: Selection of the machining process of aluminum alloy castings. The selection of the subject of the study undertaken should refer to the machining process of aluminum alloy castings which would be necessary to perform a diagnosis in terms of identifying the main factors that affect the loss of the desired level of quality and occupational safety. The analysis should refer to the process within the framework of the implementation of which machines and equipment are used.

Step 2: Clarify the purpose of the study. The purpose of the implication of the developed model should be the improvement of the processing of aluminum alloy castings in the context of ensuring the expected quality of products and guaranteeing occupational safety.

Step 3: The level of modernity of the machines used for processing aluminum alloy castings. The identification of key components of the employed machines is based on the analysis of operation and

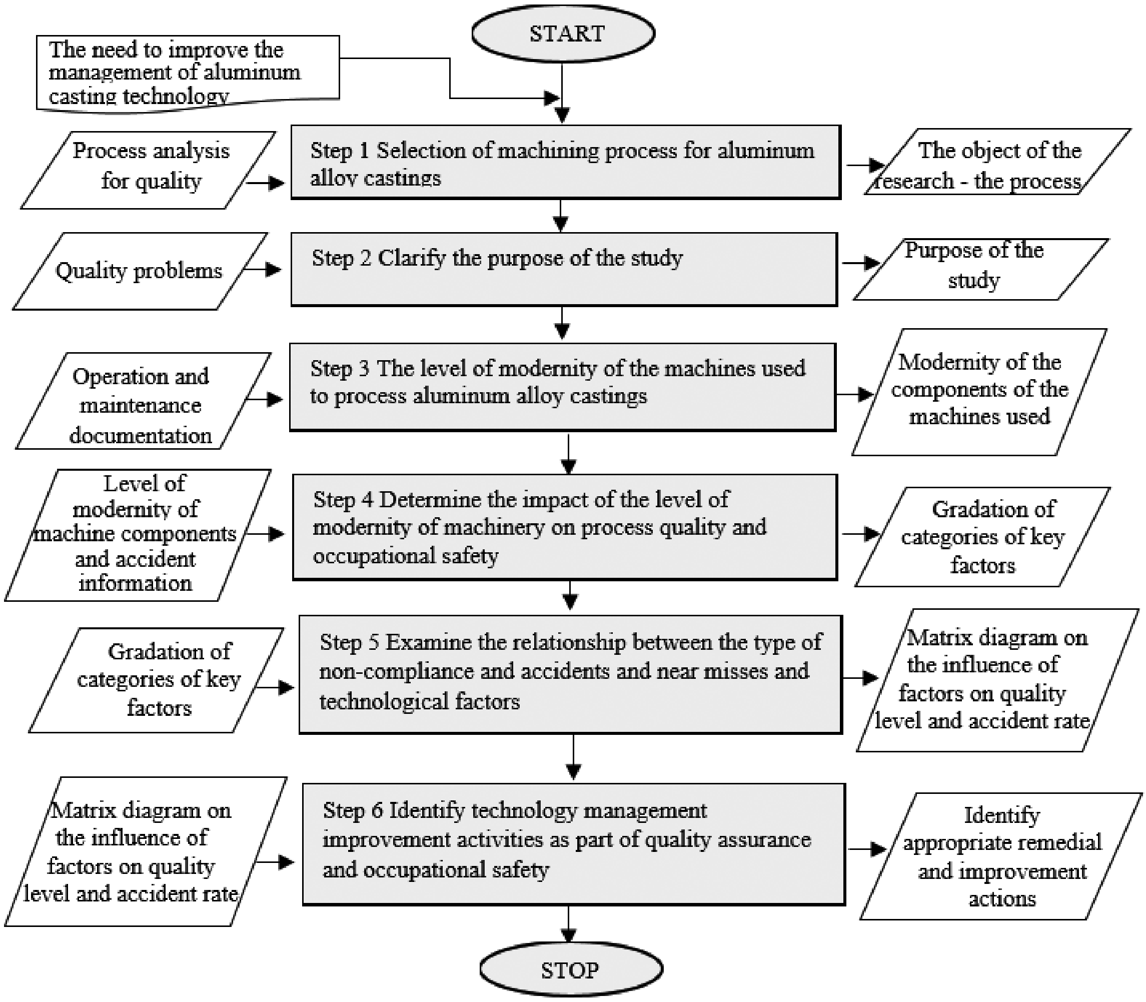

Figure 1. Diagram of the management model of the aluminum casting machining processes

maintenance documentation. This is followed by the classification of components according to the ABC technology method. To keep the study transparent, and graphically represent the results of the analysis, a Pareto–Lorenz diagram should be used. The assessment of the level of modernity is performed using Parker's five-level scale, which indicates the following levels:

- 1 – simple parts (where it is possible to produce them using craft techniques),
- 2 – parts made using techniques that have been known and unchanged for years,
- 3 – parts manufactured using technology that is based on technical knowledge,
- 4 – parts manufactured using modern technology,
- 5 – parts made with the latest technologies (found only in a particular device that is patented).

Step 4: Determine the impact of the level of modern machinery on process quality and occupational safety. Step 4 is supported by a brainstorming session with experts who present information relating to two issues: the level of quality of the machining processes performed and the quality problems within the analyzed workstation. Attention should also be paid to recorded accidents that occurred within the investigated stand, along with potential causes of these incidents (related to the condition of the machinery). In the final step, i.e., step 4, a grouping of the responses into 6M categories (i.e., man, methods, machinery, materials, management, and environment) is completed and then developed into an Ishikawa diagram.

Step 5: Investigate the relationship between the type of nonconformity and accidents, and post-attenuation events and technological factors. Create a matrix diagram showing the relationship that occurs between the identified casting nonconformities, and accidents and near-misses, and the categories of factors that contribute to the negative events. As part of the relationship assessment, the level of importance is also determined from the customer's point of view and the company's point of view, which are rated on a five-point importance scale.

Step 6: Determination of technology management improvement activities in the framework of quality assurance and occupational safety. Considering the results of the analysis from the individual steps of the model, the expert team develops improvement actions for the aluminum alloy casting machining station under study. These actions should relate to the categories under study, namely, man, material, machine, method, and management.

Model test and results

The developed model for managing aluminum casting processing is verified through its implementation in one of the business units operating in the casting industry. Data from the 3rd and 4th quarters of 2022 are used for this study.

Step 1: Selection of the aluminum alloy casting machining process. For the implementation of the study, one of the processes implemented in the manufacture of the finished product – i.e., water jet inlet – is selected. The product is cast in series from an alloy – AlSi7Mg0.3 (EN AC-42200). The finished water jet inlet has the dimensions of 1330 × 600 × 420 and weighs 66 kg; it is used in the engine and car technology industry. The rough machining process of the casting water jet inlet is studied. Pretreatment of the product is carried out using a numerically controlled lathe. Table 1 lists the characteristic parameters of the lathe used. Given the competitive nature of the data to be analyzed, the name of the machine is not indicated.

The loss of qualitative stability in the implementation of technological operations performed within the selected process, resulting in a significant increase in the number of complaints, is the main premise for the selection of the research subject.

Table 1. Properties of the numerically controlled lathe under analysis

Features of a numerically controlled lathe		Parameter
Turning diameter	over the bed	660 mm
	over the slide	380 mm
Maximum workpiece length		3000 mm
Width of the guide rail		460 mm
Spindle throughput		86
Spindle passage after hydraulics		72 mm
Spindle speed range		100–1600 RPM
Hydraulic head		6-tool
Tool size		25×25 mm
Tailstock bushing extension		235 mm
Main motor power		11 kW
Cooling pump power		250 W
Weight of the machine		4900 kg

Step 2: Clarification of the research objective. The purpose of the undertaken analysis is to improve the process of rough machining of inlet castings in terms of increasing and stabilizing the level of quality of the finished products produced, along with ensuring occupational safety.

Step 3: The level of modernity of the machines used for processing aluminum alloy castings. Based on the operation and maintenance records of the selected lathe, its individual components are identified. They are then classified into three categories: A, B, and C. Category A includes the main sub-assemblies that largely determine the result. Category B refers to sub-assemblies that support the operation of the machine, while category C relates to the parts of the subassembly that protect the operation of the machine. The subassemblies are then evaluated on Parker's five-point scale. The classification and evaluation of the separated subassemblies are indicated in Table 2.

Table 2. Degree of modernity of the components of the analyzed numerically controlled lathe

No	Segment	Components of the machine	Evaluation
1.	A	Program	4
2.		Control panel	4
3.		Control system	5
4.		Tool used	3
1.	B	Manipulator	2
2.		Slide	2
3.		Drive system	3
4.		Hydraulic system	3
1.	C	Machine housing	2
2.		Machine base	3
3.		Cooling system	3
4.		Lubrication system	2
5.		Chip transport	2

The main components of the analyzed lathe, which significantly affect the outcome of technological operations, mostly received a grade of 4. In this segment, there were also grades of 5 and 3 points. The distribution obtained in segment A indicates that the lathe's components were manufactured using the latest available technologies. On the other hand, the components of the lathe classified in segments B and C were mainly evaluated at the level of 2 points, that is, they were found to be made using techniques that have been known and unchanged for years.

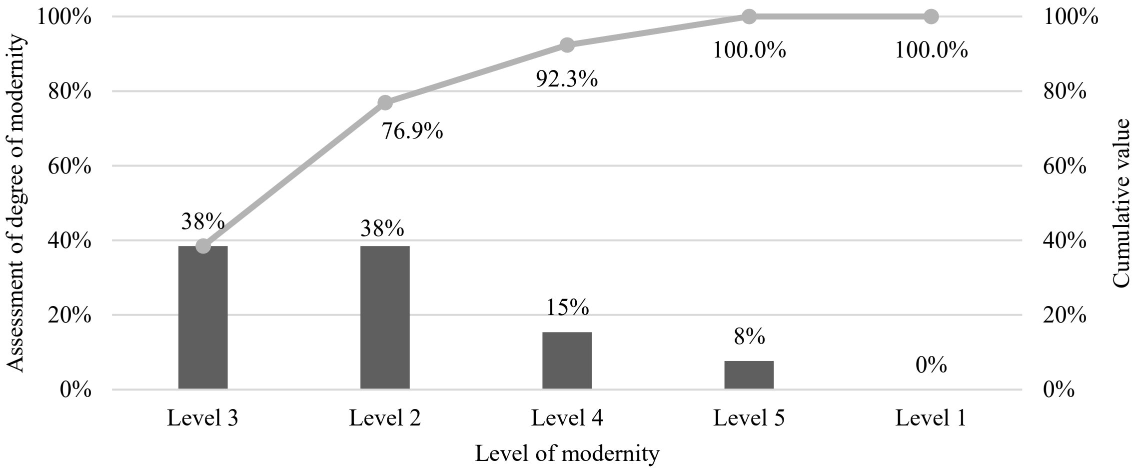

Figure 2. Level of modernity of the lathe station

To better understand and facilitate the interpretation of the results of the assessment of the degree of modernity (according to the Parker scale) of the lathe bench under study, an analysis is performed using a Pareto–Lorenz diagram. A graphical representation of the assessment results is shown in Figure 2.

The results of the assessment of the level of modernity, illustrated by means of a Pareto–Lorenz diagram, indicate that the components of the studied machine are rated equally as the third and second levels of modernity (level 3 and 2 – 38% of the machine's subassemblies). Of the 13 specified machine components, two are assigned to level 4 of modernity (program and control panel) and one component to level 5 of modernity (control system).

Step 4: Determination of the impact of the level of modernity of machinery on process quality and occupational safety. Step 4 is carried out by the following employees in cooperation: the production manager, quality control manager, and foundry department manager. These employees analyze the quality problems caused by the current state of the numerically controlled lathe and collect data on dangerous situations and accidents at work. As part of the implementation of the brainstorming session that supports step 4, employees considered the causes of two issues: "poor quality of casting pretreatment" and "accident and potential accident situations." The generated answers are grouped into 6M categories (man, material, machine, method, management, and environment) and presented in Ishikawa diagrams. The causes of the two analyzed situations are shown in Figures 3 and 4.

The issue of low levels of quality in workpiece pretreatment is a complex quality problem. Ensuring an adequate level of quality is influenced by a number of factors from the listed six areas. Consideration of the key factors contributing to the loss of quality stability of a technological operation identified the machine and management areas as those with the greatest impact. The distinguished factors in the machine area indicate that the maintenance service does not ensure the proper condition of the analyzed lathe, which would allow it to maintain proper operation and ensure its availability. Exercising day-to-day management of the lathe's spare parts also contribute to exacerbating the problem. Experts identified inadequate maintenance and the technical condition of the lathe as an important cause of the problem, according to the relationship that exists between machinery and equipment and the production process. The provision of proper technical infrastructure is essential to the proper operation of the production process. In the area of management, experts drew particular attention to the lack of verification of the effects of training by management. Evaluation of the effectiveness of the training process provides information on the strengths and weaknesses of employees in the context of the necessary knowledge for specific work positions, which additionally allows for checking of the effectiveness of the implementation of the training and the relevance of the content provided. Training for production employees is one of the primary mechanisms through which optimization is effective; additionally, it enables the implementation of the concept of continuous improvement.

In terms of ensuring a suitable work environment, experts analyzed the factors that affect accidents and potential accident situations at the lathe workstation under study. The work environment depends on a variety of intangible and tangible factors that form an integral part of the operation of any

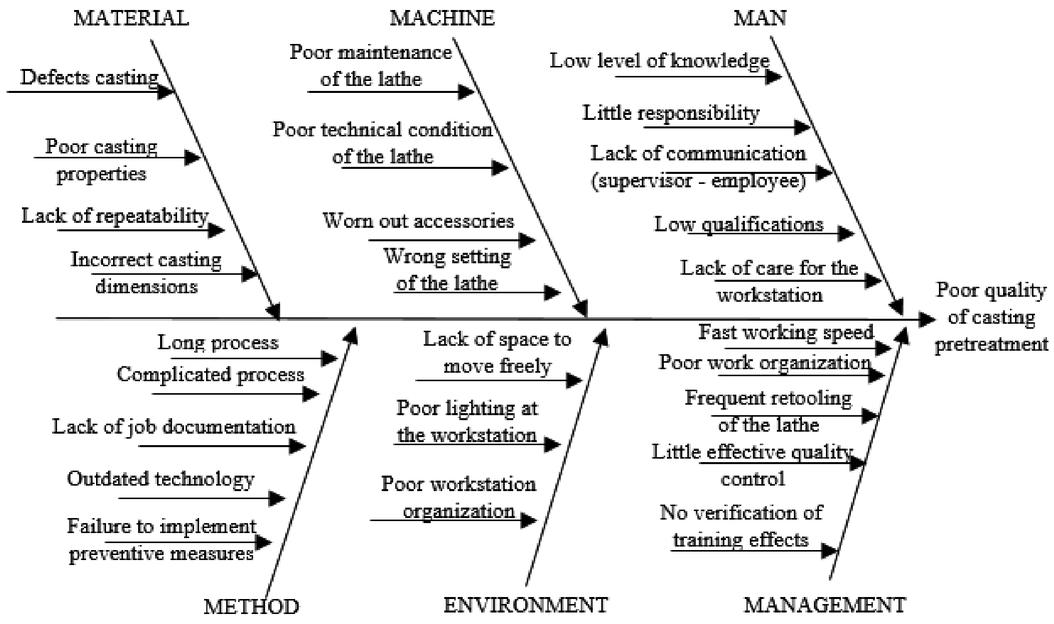

Figure 3. Analysis of the causes of poor quality of pretreatment of the workpiece

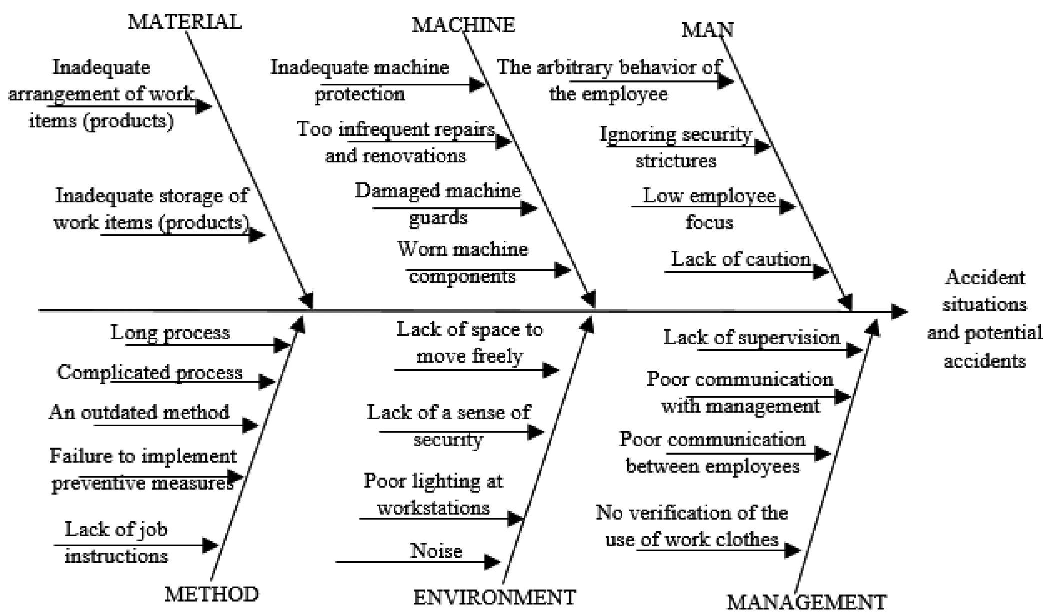

Figure 4. Analysis of the causes of accidental and potentially accidental situations

manufacturing enterprise and affect economic performance, satisfaction, and employee health. The factors to which special attention should be paid are categorized as machine and man. The inadequate condition of the machine affects not only the first analyzed problem but also occupational safety. With regard to the man category, reckless behavior of employees and failure to follow health and safety rules are frequent causes of risky incidents. The reason for this may be the lack of sufficient supervision by management.

Step 5: Examine the relationship between the type of nonconformities and accidents, and near-misses and technological factors. The result of the analysis of the relationship occurring between the nonconformities of the workpiece, and near-misses and accidents, and the groups of factors that cause them is illustrated using the matrix diagram of Table 3. A five-point scale is used to assess the importance of key nonconformities to the purchaser of the workpiece and the importance of near-misses and accidents to the business owner. Based on the strength of the relationship, the level of gradation of each category of factors (6M) is found for determining effective improvement measures for the aluminum casting machining process.

Table 3. Influence of each group of factors on the occurrence of nonconformities and irregularities

Defect	Level of significance	Man	Machine	Management	Method	Material	Environment	Modernity of the machine	Technology
	Poor quality of casting pretreatment								
Poor surface roughness	4	5	5	3	4	5	3	2	3
Wrong dimensions	5	5	5	4	4	3	3	2	3
Incomplete machined product	5	5	4	4	3	2	3	2	3
Chipping	4	4	4	3	3	3	3	3	3
Scratches	3	4	4	3	3	3	3	3	3
Burns	3	5	4	3	3	3	3	3	3
Chips	3	4	4	3	3	3	3	3	3
Total number of products	–	241	264	210	197	205	163	–	–
Ranking	–	II	I	III	V	IV	VI	–	–
	Accident and potential accident situations								
Accidents and near-misses	5	5	5	4	4	1	1	4	4
Total	–	8	3	1	1	0	0	5	5
Ranking	–	I	II	III	IV	V	VI	–	–

In Table 3, the types of critical nonconformities are ranked, starting with the most troublesome defects in terms of frequency of occurrence and the effects of their presence.

An analysis of the strength of the relationship makes it possible to detect groups within which factors have the greatest impact on the studied problem in the enterprise. With regard to the low level of quality of pre-processing of the workpiece, the key influence on the presence of critical nonconformities is shown by factors classified into two categories: machine and human. The rating of the importance of the influence of both categories on the distinguished nonconformities is in the range from 4 to 5, which indicates the significant importance of these categories in the context of maintaining the quality stability of the analyzed technological operation. The two distinguished categories are also assigned a significantly large number of products in which nonconformities are identified.

The study shows a strong relationship between the accident and potential accident situations and the category of man and machine factors. Accident factors categorized in the man group contributed to 8 hazardous incidents, which accounted for 61% of all accident and near-miss situations. Factors in the machine category represent the second group of factors generating hazardous situations. During the studied period, the condition of the lathe contributed to 23% of accidents and potential accident situations.

In the ranking of the importance of the influence of the category of factors on the occurrence and severity of the two analyzed problems, the third place is assigned to the management category. Factors in this category significantly influenced the severity of the loss of quality stability of casting pretreatment.

Step 6: Identify improvement activities of technology management in the framework of quality assurance and occupational safety.

Based on the analysis of two problems related to the workstation, where the main machine is a numerically controlled lathe, the staff team proposed corrective actions. In the area of man and machine, the measures proposed are to implement periodic training in the operation of the lathe, the correct execution of technological operations, and work safety. It is proposed that the training should end with tests to check the acquired knowledge of the employees. Further improvement activities concerned the development of health and safety instructions and workstation instructions. The purpose is to define a set of rules relating to the way of proceeding within the analyzed workstation, so that activities are performed in accordance with technology and compliance with the principles of occupational safety and health. The work team also proposed the implementation of constant inspections and maintenance, as well as the provision of convenient access to appropriate tooling and improvement of lathe settings. Additional measures directed towards the elimination of critical factors from the management group are the implementation of a control system and the provision of constant supervision of workers.

Thanks to the implementation of an in-depth analysis of the factors influencing the problem highlighted in the study, it is possible to identify adequate and effective improvement measures.

Summary and conclusion

In the current era of the fourth industrial revolution and globalized reality, foundry companies wishing to maintain a stable market position should conduct mature management of their technologies and resources. The ability of an organization to adapt immediately and effectively to a turbulent market is an important aspect in terms of competitiveness. The ability to make a sound assessment of the organization's situation and market changes has also become fundamental, which supports the broader development and maintenance of market advantage. Therefore, the purpose of the study was to build a universal model of quality management support, which allows for the effective implementation of a wide-ranging research path supporting the evaluation of the relationship between the degree of modernity of product processing technology, the quality of the final product, and the level of occupational safety. The modeling of the wide-threaded path of investigation made it possible to compile the obtained information from different areas of the enterprise.

Verification of the developed model was carried out by implementing it in one of the lathe stations within which pre-processing of a water jet inlet casting, which is used in the automotive industry, was implemented. A practical test of the quality management support model confirmed that the practice of conducting analysis of the level of modernity of infrastructure with its application contributed to the identifying of critical machine components, examining factors affecting the quality of technological operations, and reducing uncertainty and the risk of risky events, alongside a conducting of activities in line with the concept of continuous improvement. The course of action detailed in this model makes it possible to determine the relationships that exist between key categories of factors and critical product defects and accidents and near-misses. The implementation of this analysis also enables the development of adequate improvement measures within the studied position. It was proposed to implement periodic training with a knowledge test, the development of health and safety instructions and workstation manuals, and the implementation of constant inspections and maintenance, as well as the provision of convenient access to appropriate tooling and improvement of lathe settings. An additional improvement measure was to implement a control system and ensure constant supervision of workers.

The developed model of quality management support is a useful tool for manufacturing enterprises, which supports management and helps to take an effective development strategy for the enterprise that ensures the expected level of quality and safe working conditions. Future research directions will concern the implications of the model within the other workstations of the waterjet inlet production process.

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