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CREATING COMPETITIVE ADVANTAGE BASED ON A QUALITY-COST MODEL FOR IMPROVING CAST PRODUCTS

Karolina CZERWIŃSKA[1], Andrzej PACANA[2*], Łukasz RĘBISZ[3], Tomasz GAŁACZYŃSKI[4], Jan MUCHOWSKI[5]

[1] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics; k.czerwinska@prz.edu.pl, ORCID: 000-0003-2150-0963
[2] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics; app@prz.edu.pl, ORCID: 0000-0003-1121-6352
[3] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics; lr@prz.edu.pl, ORCID: 0000-0002-7689-8860
[4] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics; tomasz.galaczynski@global.lmco.com, ORCID: 0009-0007-8628-8445
[5] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics; j.muchowski@prz.edu.pl, ORCID: 0000-0001-5200-2057
* Correspondence author

Purpose: The aim of the study was to develop a quality and cost model for improving cast products, which supports optimisation activities and the resolution of quality issues in a structured manner.
Design/methodology/approach: The model utilises a sequential combination of the following techniques: Pareto chart correlated with the ABC principle, ranking, brainwriting, Ishikawa diagram (5M+E), five-point Likert scale, and matrix diagram.
Findings: During the proceedings, the main causes of critical non-compliance of castings were identified. These were: insufficient mould temperature, poor mould venting, insufficient mould filling temperature, incorrect gating system, excessive mould and core moisture.
Research limitations/implications: Future work will focus on expanding the model towards its integration with real-time data and broadening analyses related to quality assurance costs. A limitation of the model is the need for access to historical data, which is the starting point for the analyses.
Practical implications: The model has been verified in practice, confirming its correctness and usefulness in solving quality problems, taking into account the quality-cost relationship. The implementation of the model's assumptions in foundry companies will assist management in improving complex foundry processes, leading to the creation of competitive advantage.
Originality/value: The model includes an integral methodological configuration that allows for assessing the significance of the causes of identified critical non-conformities in terms of quality and cost, and provides structured support for optimisation activities and solving quality issues.
Keywords: mechanical engineering, casting defects, leak testing, quality improvement, management and quality.
Category of the paper: Research paper.

1. Introduction

The dynamic changes taking place in the external environment of industrial enterprises are placing ever greater demands on organisations in terms of development and presenting them with increasingly difficult problems to solve. One of the key conditions for achieving market success and competitive advantage is the design and implementation of processes tailored to specific production capabilities and needs (Gajdzik, Wolniak, 2022; Pacana, Czerwińska, 2018). Products should not be implemented at any cost, paying attention only to the costs associated with a given implementation and the amount of potential profits (Khan et al., 2022). When undertaking implementation activities, the manufacturer should be confident that the expected level of product quality will be ensured and that the rate of return on the implemented product will be high enough to offset the costs incurred (Stawiarska et al., 2021; Ingaldi, Mazur, 2022).

In an era of intense and progressive globalisation in the field of production, quality has become an important distinguishing feature of industrial companies operating on the market. It is closely related to the manufacture of products, their sale and the level of costs incurred by the organisation. In the vast majority of cases, the buyer's decision to accept or reject a product determines the success or failure of the manufacturer or service provider (Dornelles, Sellitto, 2015; Gramegna, 2017). These issues have an impact on building a company's position in a competitive market. On the road to success, it is also important to build a strong brand through continuous improvement, consistent action and rapid response to market changes (Gijo et al., 2014; Siekanski, Borkowski, 2003).

Companies wishing to maintain a stable level of quality while increasing the economic efficiency of their resources and processes should implement effective management methods (Pietraszek, Skrzypczak-Pietraszek, 2014; Czerwińska et al., 2025). This requires, on the one hand, diagnosing whether the activities carried out so far have brought the expected results and, on the other hand, taking measures related to quality improvement while focusing on the reasonable use of production resources (Malinowski et al., 2013). Such a development strategy also affects the effectiveness of the tasks undertaken by the company and the building of a stable market position (Klimecka-Tatar et al., 2021).

An important aspect of managing a foundry company is striving to improve quality in the specialised process of casting (Bris et al., 2021). This involves technological parameters that can affect the quality of the finished product. The most significant problem in the production process of cast products is the inability to simultaneously control all the determinants of the technological process quality. This fact makes casting a very complex technique, and the implementation of individual stages of production in this technology is associated with many difficulties (Pacana, Czerwińska, 2023; Borkowski et al., 2016). As part of quality improvement and minimising deviations from the desired quality criteria, the measures taken increasingly concern not only the testing and analysis of finished castings (with particular attention to non-conformities) but also the prediction and prevention of undesirable events (Prasad et al., 2016; Pacana, Czerwińska, 2023a). The possibility of reducing the level of potential costs associated with exercising full quality control over batches of manufactured castings encourages this approach. The desire to reduce costs may prompt changes, but full control contributes to longer production processes and is a labour-intensive task, the benefits of which in terms of quality assurance may not outweigh the potential slowdown (Khan et al., 2023; Pietraszek et al., 2020). It is crucial to identify critical products and related non-conformities. Analysis of these problems and their determinants will allow for effective maintenance of a stable level of quality of the cast product (Ulewicz, Novy, 2019; Greń, Zaziębło, 2019).

The aim of the study was to develop a quality and cost model for improving cast products. The implementation of the model's assumptions in foundry companies will assist management in carrying out complex processes leading to the creation of competitive advantage. The model contains an integral methodological configuration that allows for the assessment of the significance of the causes of identified critical non-conformities in terms of quality and cost, and provides structured support for optimisation activities and the resolution of quality issues. The model uses a sequential combination of the following techniques: Pareto diagram correlated with the ABC principle, ranking, brainwriting, Ishikawa diagram (5M+E), five-point Likert scale and matrix diagram.

2. Methods

The quality and cost improvement model for products was developed to improve quality by minimising deviations from the desired quality criteria and stabilising the production process for cast products while maintaining cost efficiency. The application of the model boils down to analysing the product by identifying and solving critical quality problems, which in most cases are product non-conformities. The procedure presented in the model allows for the identification of critical non-conformities, whose presence contributes most to the instability of the quality process and at the same time generates the highest costs. The model is based on the sequential integration of methods and techniques such as: the Pareto Lorenz diagram correlated with the ABC method, non-verbal brainstorming (Brainwriting), the Ishikawa diagram (according to the 5M+E principle), a balanced five-point rating scale, and a matrix diagram. The individual stages of the model are presented in Figure 1. The model diagram also takes into account the methods and techniques dedicated to each stage of the process.

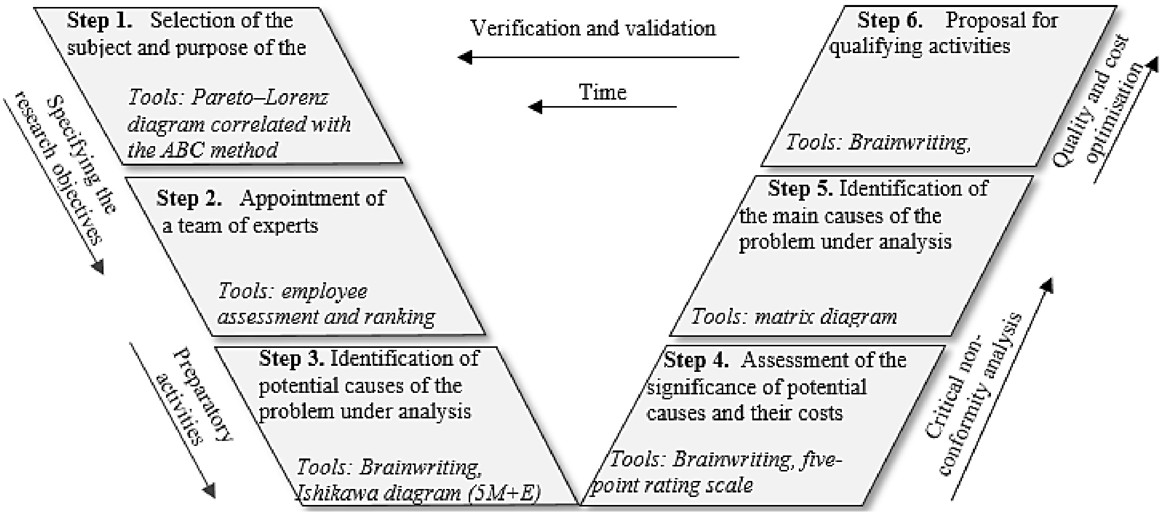


Figure 1. Diagram of the structure of a quality-cost model for improving cast products.

Source: own study.

The individual stages of the model's implementation are presented in the following subsections.

2.1. Selection of the subject and purpose of the research

The subject and purpose of the research should be specified by an authorised entity (expert). Defining the subject of the research allows researchers to focus their attention on a specific quality issue that will be examined, analysed and evaluated using appropriately selected research methods (Czerwińska, Pacana, 2025). Due to the purpose of the model, the subject of the research may be a cast product whose manufacturing process has lost its quality stability or a selected type of non-compliance (critical in terms of severity, effects, frequency and costs of occurrence). The selection of the subject of research may be supported by a non-conformity register (if kept in the company) or made using supporting tools - a Pareto Lorenz diagram correlated with the ABC method (Sułkowski, Wolniak, 2013). Next, the objective of the study corresponding to the current needs of the company should be specified. A well-defined research objective will guide the entire work and assist in the interpretation of the results. The application of the developed model supports the achievement of objectives related to:

- identification of non-conformities between the actual state and the expected standard, which may relate to a product or process,
- analysis of quality issues,
- analysis of the causes of critical non-conformities (root causes),
- analysing the cost severity associated with the presence of critical non-conformities,
- proposing adequate corrective actions while maintaining a reasonable relationship between the quality achieved and the costs of achieving it.

The accepted research objective should relate to the subject of the research and take into account the client's requirements in this regard.

2.2. Appointment of a team of experts

The team of experts analysing the problem related to quality improvement activities should consist of appropriately trained employees with extensive knowledge of the subject matter and experience in the area to be improved. The team leader coordinates tasks and supports team members (Wolniak, 2022; Ingaldi, Ulewicz 2025). The aim of the team of experts is to prevent the problem from recurring.

2.3. Identification of potential causes of the problem under analysis

This step should begin with an analysis of the current situation, taking into account the relevant area in relation to the subject and purpose of the research. These may include: processes, customer expectations, financial results, quality issues and product non-conformities. The analysis of the causes of loss of product quality stability should include the results of a specialist product diagnosis (Czerwińska et al., 2021). The task of the experts is to identify all the probable causes of the problem under investigation. This activity should be supported by a brainstorming session. This will make it possible to generate a large number of ideas. It is recommended to use a written form of brainstorming, as this will avoid the tensions and conflicts that can arise in a classic brainstorming session. The results of the session should be visualised and logically grouped according to the rules of creating an Ishikawa diagram in a 5M+E configuration (Wolniak, 2016).

2.4. Assessment of the significance of potential causes and their costs

In this step, the team of experts evaluates the potential causes of the problem under investigation, taking into account their impact on reducing quality and the associated costs. The assessment should use a five-point Likert scale, where, in relation to the model, the extreme points mean: 1 – the cause has a very small impact on the problem and generates very low costs, 5 – the cause has a very large impact on the problem and generates very high costs. In order to avoid conflicts in assigning ratings, it is worth supporting this step with a brainwriting tool. Individual ratings should be entered into an Ishikawa diagram or, for greater clarity, placed in a summary table.

2.5. Identification of the main causes of the problem under analysis

The main causes of the analysed problem should be understood/recognised as those that determine the occurrence of a quality problem and at the same time significantly increase costs. A matrix diagram should be used to identify critical causes in the quality-production cost relationship. The analysed causes of the quality problem should be placed in the diagram based on expert assessments in the quality and cost categories. Causes located in the critical area should be considered the main causes for further analysis.

2.6. Proposed improvement measures

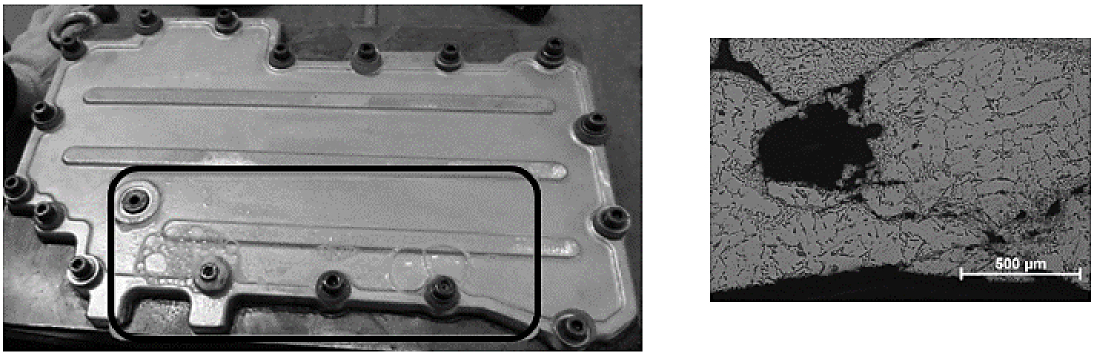
Improvement measures should include corrective and preventive actions. With regard to the root causes of quality problems, corrective actions should be developed and implemented to eliminate the root causes of existing irregularities in order to prevent their recurrence (Gajdzik, Sitko, 2016). Next, a team of experts should develop preventive measures in line with a proactive approach to permanently eliminate the potential causes of problems. Improvement measures should be developed using brainwriting.

3. Results and discussion

The developed model was tested in practice by applying it to a foundry located in south-eastern Poland. In order to test the model, production information was analysed, including historical data from the production process (production status and progress, number of units produced, material consumption, machine and employee working time, as well as data on quality and costs) and information on complaints and quality issues. The information analysed was from the first quarter of 2025.

The first step was to define the subject of the research and specify its objective. Based on data concerning the non-compliance of cast products and complaint records, a control panel cover cast using the gravity casting method from AlSi7Mg0.6 alloy was selected as the subject of the research. The design changes introduced in relation to the change in the shape and size of the casting contributed to a loss of stability in the production process, which led to the manufacture of a significant number of products outside the specified tolerance limits. The objective of the research related to the subject of the study was then specified. Analysis of the non-conformity records showed that the dominant type of non-conformity was the presence of oxides in the control panel cover. This non-conformity is identified in the leak test of castings. For this reason, the objective of the research was to identify the main causes of the presence of oxides in the control panel cover. Figure 2 shows the control cover casting with the result of the leak test and an example of a critical non-conformity in the marked area.

The next step was to appoint a team of experts. The team consisted of: chief technologist, product quality control manager, production manager, and complaints specialist. The appointed team carried out the subsequent stages of the analysis.



a) b)

Figure 2. a) Subject of testing with non-compliance revealed in the water sample, b) example of critical non-compliance – leakage (oxide inclusion through the casting wall).

Source: own work.

The next step was to identify the potential causes of oxygen inclusions in the casting. The probable causes of the quality problem were gathered by the team of experts during a brainwriting session. The result of the session – the ideas generated – were grouped and plotted on an Ishikawa diagram in a 5M + E configuration, taking into account six categories: man, machine, material, method, management, environment (Figure 3).

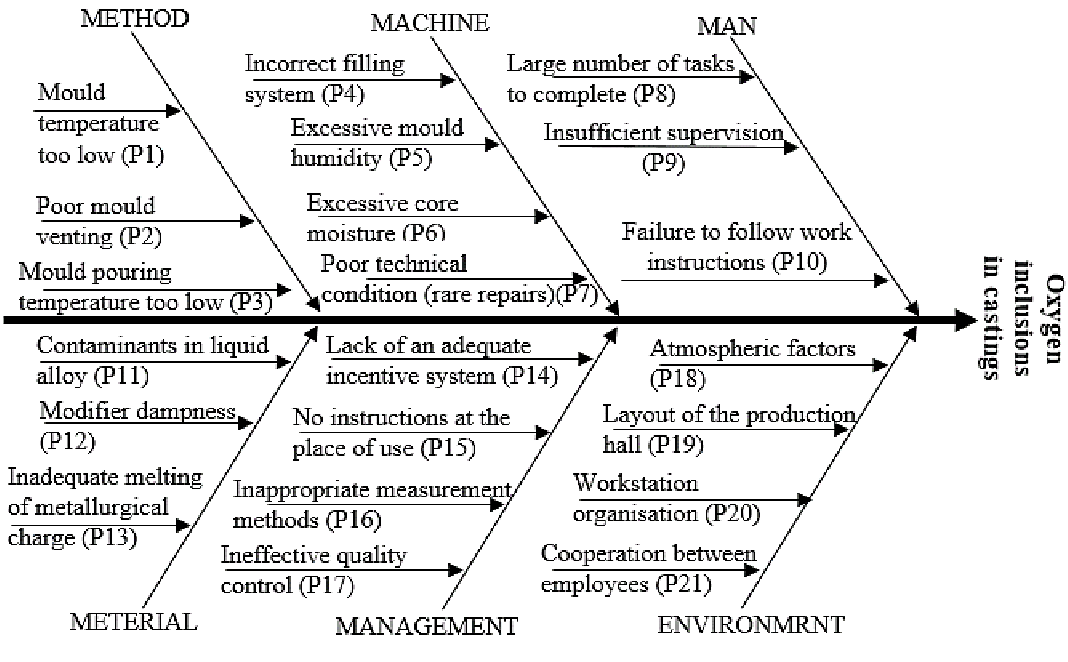


Figure 3. Ishikawa diagram for the problem of oxygen inclusions in castings.

Source: own work.

When assessing the significance of potential causes of the problem in the products and their costs, the team of experts adopted a five-point rating scale (1 – the cause has a very small impact on the problem and generates very low costs; 5 – the cause has a very large impact on the problem and generates very high costs). Assessment sheets were prepared on which team members anonymously assigned ratings. The final ratings of potential causes (Table 1) are the result of the average of the ratings assigned, rounded to the nearest whole number.

Table 1.
Assessment of the importance of potential causes and the costs of their occurrence

The analysed area	Identification of the potential cause	Assessment of the impact of potential causes on the analysed non-compliance	Assessment of the level of costs incurred due to the presence of potential causes of the problem
Method	P1	3	1
	P2	3	3
	P3	5	3
Machine	P4	4	3
	P5	5	4
	P6	5	4
	P7	2	4
Man	P8	2	2
	P9	1	3
	P10	2	2
Material	P11	4	2
	P12	5	2
	P13	4	2
Management	P14	2	2
	P15	2	3
	P16	3	2
	P17	3	2
Environment	P18	4	1
	P19	3	1
	P20	1	1
	P21	2	1

Source: own work.

In order to identify the main causes of the problem, i.e. those causes that significantly affect the loss of the expected level of quality and generate significant costs, the team of experts used a matrix diagram. The graphical representation of the assessment results on a four-quadrant matrix grid provides information that facilitates the analysis of the critical distribution of the causes of the problem. The result is shown in Figure 4.

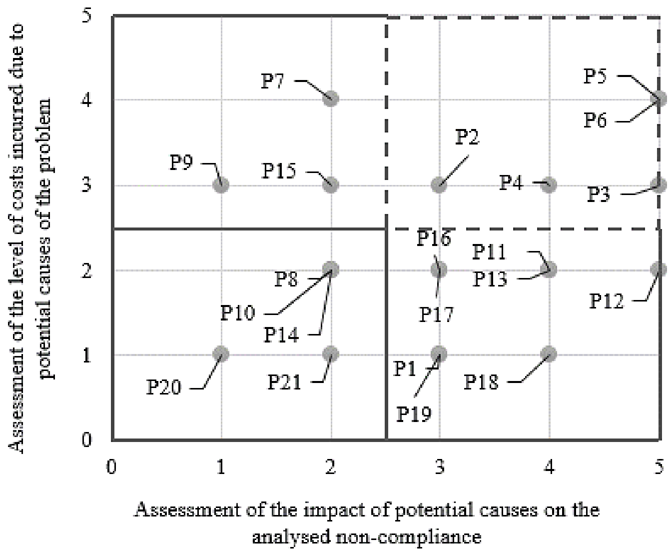


Figure 4. Assessment of the impact of potential causes on the occurrence of the investigated casting non-conformity in terms of quality and cost.

Source: own work.

The critical area, i.e. the upper right field marked with a dotted line, indicates the main causes of the quality problem. The following potential causes are located in this field: P1 – mould temperature too low, P2 – poor mould venting, P3 – mould filling temperature too low, P4 – incorrect gating system, P5 – mould moisture too high, P6 – core moisture too high. Table 2 summarises the impact of potential causes on the presence of the analysed non-conformity.

Table 2.
Synthetic analysis of the impact of potential causes on the presence of the analysed non-compliance

Possible reason		Synthetic description of the impact
P1	mould temperature too low	Too low a mould temperature affects the crystallisation time. Slow solidification increases the porosity of the alloy and the presence of oxides in the casting.
P2	poor mould venting	Incorrect selection of vacuum parameters causes improper venting of the mould, which 'traps' air in the casting, thereby increasing gas porosity.
P3	mould filling temperature too low	If the mould filling temperature is too low (the liquid alloy is kept in the ladle or heating furnace for too long), this may lead to an increase in its gas content.
P4	incorrect filling system	Its incorrect design of the pouring system, especially in castings characterised by complex geometry and varying wall thicknesses, contributes to increased porosity in the more massive parts of the casting.
P5	excessive mould humidity	Excessive moisture in the mould or casting core causes blisters to form in castings, as water evaporates rapidly on contact with hot metal.
P6	excessive moisture in the cores	

Source: own work based on: (Parlak, Emel, 2023; Song et al., 2021; Lichy et al., 2016).

After conducting a qualitative and cost analysis and identifying the main causes of leakage (oxide inclusions through the wall) in the control panel cover casting, a brainwriting session was held to generate a comprehensive list of improvement measures. The improvement measures included the following guidelines:

- selection of appropriate process parameters (analysis of vacuum parameter selection),
- simulation of mould cavity filling and solidification,
- introduction of precise stage and final control,
- constant monitoring of mould temperature, mould and core moisture levels,
- reconstruction and optimisation of the mould gating system,
- implementation of the TPM (Total Productive Maintenance) method, in order to achieve maximum efficiency in the use of machinery and employee engagement,
- development of workstation instructions in the Foundry area,
- training of foundry department employees and creation of a quality-oriented organisational culture.

The aim of implementing the proposed improvement measures was to improve the quality of cast products while minimising costs related to repairs, complaints and disposal of non-compliant products. The implementation of the specified measures in the analysed company will bring a wide range of benefits in terms of quality, costs, technology and management.

The developed model can support management in the event of quality problems. The application of the developed model enables analyses to be carried out while maintaining the quality-cost relationship. In the industrial sphere, this relationship is based on an analysis of the sum of all expenses related to the detection and correction of errors and the prevention of defects. Optimisation in this relationship involves investing in corrective, preventive and evaluative measures, which in the long term significantly increases and stabilises product quality and reduces costs associated with quality issues and failures (internal and external), leading to greater customer satisfaction and competitive advantage.

4. Summary and conclusion

The issue of leaks in aluminium alloy products is a serious one, given the current increase in requirements for the service life of cast components, which results from their use, increasingly aware consumers, growing competition, pressure for sustainable development and technological progress. For this reason, it was reasonable to set the goal of developing a quality and cost improvement model for cast products. The model contains an integral methodological configuration that makes it possible to assess the degree of significance of potential causes of identified critical non-conformities in terms of quality and cost, and in a structured way supports optimisation activities and the resolution of quality issues.

A practical verification of the developed quality and cost model for improving cast products was carried out, which confirmed its correctness and usefulness in the industrial sector. The analysis concerned the casting of a control panel, whose manufacturing process had lost its quality stability due to design changes. The critical non-conformities were identified as oxide inclusions throughout the casting wall, causing leaks. In the further course of the proceedings, the main causes of non-conformities were identified. These were: too low mould temperature, poor mould venting, too low mould filling temperature, improper gating system, too high mould and core moisture content. Improvement measures appropriate to the situation and capabilities of the company were also proposed. It was proposed to implement specific technological changes in the examined process, implement TPM, develop workstation instructions in the foundry area and conduct training.

The proposed model can be a component of activities supporting quality management processes. It is a logical model and relatively easy to apply in practice, and at the same time, this analysis significantly increases the amount of information about the analysed problem. Future research directions will focus on implementing the presented model in relation to products in the company in accordance with the concept of continuous improvement. Future work will focus on expanding the model towards integration with data collected and functioning in real time.

References

1. Borkowski, A., Ingaldi, M., Sygut, P., Klimecka-Tatar, D. (2016). Stability of the casting process according to the method BOST. *Manufacturing Technology, Vol. 16, Iss. 1,* p. 26.
2. Bris, P., Hyza, J., Sedlacek, M., Kramna, E. (2021). Use of quality management to optimize foundry industry processes. *Acta Polytechnica Hungarica, Vol. 18, Iss. 6,* pp. 213-232.
3. Czerwińska, K., Bełch, P., Hajduk-Stelmachowicz, M., Siwiec, D. Pacana, A. (2021). Improvement of graphitization process of aluminum products. *Przemysł Chemiczny, Vol. 100, Iss. 12.* Sigma-N OT sp. z o.o., pp. 1191-1193. DOI: 10.15199/62.2021.12.8
4. Czerwińska, K., Pacana, A. (2025). Improving the surface condition of the casting of the control panel cover. *Tehnički vjesnik, Vol. 32, Iss. 1*, pp. 338-346. DOI: https://doi.org/10.17559/TV-20220106194242
5. Czerwińska, K., Pacana, A., Rzucidło, A., Radwański, R. (2025). A model for shaping reverse logistics in manufacturing companies using indicator analysis. *Scientific Papers of Silesian University of Technology. Organization & Management, no. 223*, pp. 23-35. DOI: http://dx.doi.org/10.29119/1641-3466.2025.223.2
6. Dornelles, J.V., Sellitto, M.A. (2015). Overall equipment effectiveness (OEE) for diagnosis and productivity improvement in the foundry industry. *Revista Geintec-Gestao Inovacao E Tecnologias, Vol. 5, Iss. 3*, pp. 2366-2379. DOI: 10.7198/S2237-0722201500030013
7. Gajdzik, B., Grabowska, S., Saniuk, S. (2021). Key socio-economic megatrends and trends in the context of the industry 4.0 framework. *Forum Scientiae Oeconomia, Vol. 9, Iss. 3*, pp. 5-22. DOI: 10.23762/FSO_VOL9_NO3_1
8. Gajdzik, B., Sitko, J. (2016). Steel mill products analysis using qualities methods. *Metalurgija, Vol. 55, Iss. 4.* Hrvatsko Metalursko Društvo (HMD), pp. 807-810.
9. Gajdzik, B., Wolniak, R. (2022). Influence of Industry 4.0 Projects on Business Operations: literature and empirical pilot studies based on case studies in Poland. *Journal of Open Innovation: Technology, Market, and Complexity, Vol. 8, Iss. 1*, p. 44. https://doi.org/10.3390/joitmc8010044
10. Gijo, E.V., Bhat, S., Jnanesh, N.A. (2014). Application of Six Sigma methodology in a small-scale foundry industry. *International Journal of Lean Six Sigma, Vol. 5, Iss. 2,* pp. 193-211. DOI: 10.1108/IJLSS-09-2013-0052
11. Gramegna, N. (2017). Foundry 4.0. Digitization in foundry. Process control and non quality costs. *Metallurgia Italiana, Iss. 4*, p. 57.
12. Greń, A., Zaziebło, P. (2019). Zastosowanie wybranych narzędzi zarządzania jakością w celu zwiększenia efektywności maszyn w przedsiębiorstwie produkcyjnym. *Zarządzanie Przedsiębiorstwem, Vol. 22, no. 3*. Polskie Towarzystwo Zarządzania Produkcją, pp. 11-18.

13. Ingaldi, M., Mazur, M. (2022). Evaluation of the Technological Modernity of the Machines used in the Metallurgical Industry. *Materials Research Proceedings, Vol 24.* Materials Research Forum LLC, pp. 118-125. https://doi.org/10.21741/9781644902059-18
14. Ingaldi, M., Ulewicz, R. (2025). The role of AI in digital leadership-new competencies of leaders. *Polish Journal of Management Studies, Vol. 31, No. 2*. DOI: 10.17512/pjms.2025.31.2.07
15. Khan, Ma., Ali, Mk., Sajid, M. (2022). Lean implementation framework: a case of performance improvement of casting process. *IEEE Access, Vol. 10*, pp. 81281-81295. DOI: 10.1109/ACCESS.2022.3194064
16. Khan, S.S., Sajid, M., Wasim, A., Sheheb, E., Abdalla, H., Hussain, S. (2023). A lean knowledge-based decision support system for cost estimation in the foundry industry. *Brazilian Archives of Biology and Technology, Vol. 66.* DOI: 10.1590/1678-4324-2023220658
17. Klimecka-Tatar, D., Ingaldi, M., Ulewicz, R., Dwornicka, D. (2021). *Preparation for implementation of Industry 4.0 in small and medium-sized enterprises of metal industry.* METAL 2021-30th Anniversary International Conference on Metallurgy and Materials, Conference Proceedings. Tanger, Ostrava, pp. 1435-1459.
18. Lichy, P., Kroupova, I., Radkovsky, F., Nguyenova, I. (2016). *Possibilites of the controlled gasification of aluminum alloys for eliminating the casting defects.* Metal 2016: 25th Anniversary International Conference on Metallurgy and Materials, pp. 1474-1479.
19. Malinowski, P., Suchy, J.S., Jakubski, J. (2013). Technological knowledge management system for foundry industry. *Archives of Metallurgy and Materials, Vol. 58, I. 3*, pp. 965-968. DOI: 10.2478/amm-2013-0111.
20. Pacana, A., Czerwińska, K. (2018). Selected aspects of production control a crankshaft with a free forging method TR. *Zarządzanie Przedsiębiorstwem, Vol. 21, Iss. 1,* pp. 21-25.
21. Pacana, A., Czerwińska, K. (2023). Analysis of the technological position in relation to aluminium casting production. *Advances in Mechanical and Materials Engineering, Vol. 40*, pp. 15-21. DOI: https://doi.org/10.7862/rm.2023.2
22. Pacana, A., Czerwińska, K. (2023a). Indicator analysis of the technological position of a manufacturing company. *Production Engineering Archives, Vol. 29, I. 2,* pp. 162-167. DOI: 10.30657/pea.2023.29.19
23. Parlak, I.E., Emel, E. (2023). Deep learning-based detection of aluminum casting defects and their types. *Engineering Applications of Artificial Intelligence, Vol. 118*. DOI: 10.1016/j.engappai.2022.105636
24. Pietraszek, J., Radek, N., Goroshko, A.V. (2020). Challenges for the DOE methodology related to the introduction of Industry 4.0. *Production Engineering Archives, Vol. 26, Iss. 4,* pp. 190-194. DOI: DOI: 10.30657/pea.2020.26.33

25. Pietraszek, J., Skrzypczak-Pietraszek, E. (2014). Trans Tech Publications, Switzerland. The optimization of the technological process with the fuzzy regression. *Advanced Materials Research, Vol. 874,* pp. 151-155.
26. Prasad, S., Khanduja, D., Sharma, S.K. (2016). An empirical study on applicability of lean and green practices in the foundry industry. *Journal of Manufacturing Technology Management, Vol. 27, Iss. 3*, pp. 408-426. DOI: 10.1108/JMTM-08-2015-0058
27. Siekanski, K., Borkowski, S. (2003). Analysis of foundry defects and preventive activities for quality improvement of castings. *Metalurgija, Vol. 42, Iss. 1*, pp. 57-59.
28. Song, H.Q., Zhang, L.Y., Cao, F.Y., Gu, X., Sun, J.F. (2021). Oxide bifilm defects in aluminum alloy castings. *Materials Letters, Vol. 285*. DOI: 10.1016/j.matlet.2020.129089
29. Stawiarska, E., Szwajca, D., Matusek, M., Wolniak, R. (2021). Diagnosis of the maturity level of implementing Industry 4.0 solutions in selected functional areas of management of automotive companies in Poland. *Sustainability, Vol. 13, Iss. 9,* p. 4867. https://doi.org/10.3390/su13094867
30. Sułkowski, M., Wolniak, R. (2013). Przegląd stosowanych metod oceny skuteczności i efektywności organizacji zorientowanych na ciągłe doskonalenie. *Zeszyty Naukowe, Organizacja i Zarządzanie, Vol. 67.* Wydawnictwo Politechniki Śląskiej, pp. 63-74.
31. Ulewicz, R., Novy, F. (2019). Quality management systems in special processes. *Transportation Research Procedia, Vol. 40.* Elsevier, pp. 113-118.
32. Wolniak, R. (2016). Kulturowe aspekty zarządzania jakością. *Etyka biznesu i zrównoważony rozwój. Interdyscyplinarne studia teoretyczno-empiryczne, Vol. 1*, pp. 109-122.
33. Wolniak, R. (2022). Management of engineering teams. *Scientific Papers of Silesian University of Technology, Organization & Management, Vol. 157,* pp. 667-683. http://dx.doi.org/10.29119/1641-3466.2022.157.43