Materials Research Proceedings 34 (2023) 226-236 https://doi.org/10.21741/9781644902691-27

Method Supporting Improving Products in Terms of Qualitative-Environmental

PACANA Andrzej[1,a], SIWIEC Dominika[2,b *] and DWORNICKA Renata[3,c *]

[1]Rzeszow University of Technology, Rzeszów, Poland, ORCID: 0000-0003-1121-6352

[2]Rzeszow University of Technology, Rzeszów, Poland, ORCID: 0000-0002-6663-6621

[3]Cracow University of Technology, Kraków, Poland, ORCID: 0000-0002-2979-1614

[a]app@prz.edu.pl, [b]d.siwiec@prz.edu.pl, [c]renata.dwornicka@pk.edu.pl

Keywords: Quality, Production Engineering, Multi-Criteria Decision Method, Sustainability Development, Importance Performance Analysis, Mechanical Engineering

Abstract. Problems with product quality during negative climate changes make the continuous improvement process difficult. The search for approaches consists of methodical and possible detailed analysis areas of these types of problem types. Therefore, the objective of the article was to develop a method to analyze problems with the quality of products considering the impact on the natural environment. The method was developed by a coherent combination of selected techniques, i.e.: brainstorming (BM), Ishikawa diagram, 5M rule, multiple voting, seven-point Likert scale, and the IPA method. A method was carried out for mechanical seal of the 410 alloy, on which a porosity cluster was detected. The originality of the study is that the proposed method supports a consistent methodical analysis of any problem with the quality of products and verifies these problems in view of their impact on the natural environment. Simultaneously, the result obtained from the method determines the main causes of the problem, from which to begin improving the quality of the product considering the impact on the natural environment. This method can be applied to any product and the incompatibilities detected on them. Therefore, the method can be used in service-production enterprises to improve products in terms of qualitative-environmental.

Introduction

Obtaining expected product quality remains a challenge. This is mainly due to dynamic changes in customer requirements and escalating negative climate change [1-3]. For this reason, it is important to adequately plan the process of product production in the design phase [4,5]. However, in view of the mentioned changes in customer requirements and the essence of caring for the natural environment, it is necessary to continuously improve the products. The popular action as part of achieving the expected quality of products is quality control, e.g. non-destructive testing (NDT) [6], which in view of the waste source are more beneficial than destructive testing (DT) [7]. It results from the effectiveness of NDT research in the identification of incompatibility of products without destructive elements, therefore these tests are more environmentally friendly. The quality control of the products after which incompatibility was detected is only the first stage in improving the process. This is due to the lack of application of non-destructive testing controls to identify the causes of these incompatibilities [8-10]. Later, it is necessary to use other techniques that support analysis of the causes of product incompatibility. Popular in use are, among other quality management techniques.

For example, the authors of articles [11-13] used the Ishikawa diagram to improve the quality of products. This diagram has application in the identification of potential causes of incompatibility. Other examples are studies [13-15], which the Pareto-Lorenz analysis and Ishikawa diagram were combined. Using these tools consists of determining potential causes and then the main causes of the problem, that is, those that generate the greatest problem. The authors of the study [16] developed a universal model for improving the quality of industrial products, in which different quality management were used and combined sequentially. However, new approaches to analysis of the causes of problems with product quality problems were shown in studies [17,18]. These articles show the developed methods and models supporting the stability of the quality of materials and industrial products, where the innovation was the use simultaneously quality management tools and multi-criteria decision-making methods, e.g.: DEMATEL method, FAHP method (Fuzzy Analytic Hierarchy Process) or GRA method (Grey Relational Analysis). However, these analyzes were not aimed at improving the quality of products while caring for the natural environment. According to the authors of studies [19-21], in the era of negative climate change, customers pay more attention to the environmental friendliness of products. Therefore, it was concluded that a pro-ecological approach to product improvement is needed.

The purpose of this article was to develop a method to analyze problems with the quality of products considering the impact on the natural environment. The originality of the study is that the proposed method supports a consistent methodical analysis of any problem with the quality of products and verifies these problems in view of their impact on the natural environment. Simultaneously, the result obtained from the method determines the main causes of the problem, from which to begin improving the quality of the product considering the impact on the natural environment. A method was carried out for mechanical seal of the 410 alloy, on which a porosity cluster was detected.

New methods aimed at improving quality [22-24] in line with environmental protection inevitably bring about changes in both management systems [25-27] and associated production optimization systems [28]. Implementing these methods requires coordinated changes in various technological areas, such as special functional and protective coatings [29,30], hydraulic fluids in hydraulic systems [31-33], modification of surface layers [34] to reduce the rate of wear of interacting machine parts [35,36], and modifications of connections, including welding [37-39], to improve the integrity of structural components. These actions effectively reduce environmental pressure [40] by enhancing corrosion resistance [41-43], even in aggressive corrosive technological environments [44,45], and improving fatigue resistance [46]. Simultaneously, design changes enable increased levels of recycling of used parts and packaging materials [47]. Such multifactorial organizational and technological changes require a systematic approach to ensure the reliability and accuracy of the implemented modifications. In this regard, the methodology of experimental planning [48-50] is invaluable, as it allows for handling poorly defined variables in specific cases [51-53]. Ultimately, the introduced changes, by enhancing the quality and reliability of products and services, lead to simplified scenarios of potential failures and their consequences [54-56].

Method

The method was developed to improve the quality of products in terms of qualitative-environmental aspects. The concept of the method is based on the sequential and coherent analysis of the causes of problems with the quality of products and then the determination of the impact of these causes on the natural environment. The results of the method allow identification of the main causes of the problem, i.e.: the most contributing to the problem, and at the same time having the greatest negative impact on the environment. After testing different methods and making a literature review, it was possible to combine and use selected techniques, i.e. brainstorming (BM), Ishikawa diagram, 5M rule, multiple voting, seven-point Likert scale, and the IPA method (Importance Performance Analysis). The method was developed in five main stages, as shown in Fig.1. The characteristic of the method stage is shown in the next part of the study.

Stage 1. Choice of the subject of study and determine the purpose of the research. The subject of the study is selected by the entity (expert), where it can be, e.g. product unstable in quality or incompatibility, most occurred on products. In the proposed approach, the main incompatibility, so most often occurred. The choice of this incompatibility can be done on catalogue of incompatibility of products, which is often realized by the entity. In case of a large number of incompatibilities of different types, it is necessary to use tools supporting, e.g. Pareto-Lorenz analysis (20/80) [15]. Then, depending on the selected subject of study, it is necessary to determine the purpose of the research. The purpose is determined by the entity (expert) using SMARTER method [57]. It was assumed that purpose should refer to identifying the main causes of the problem, which will have the largest probability impact on the problem, and simultaneously will have a negative impact on the natural environment.

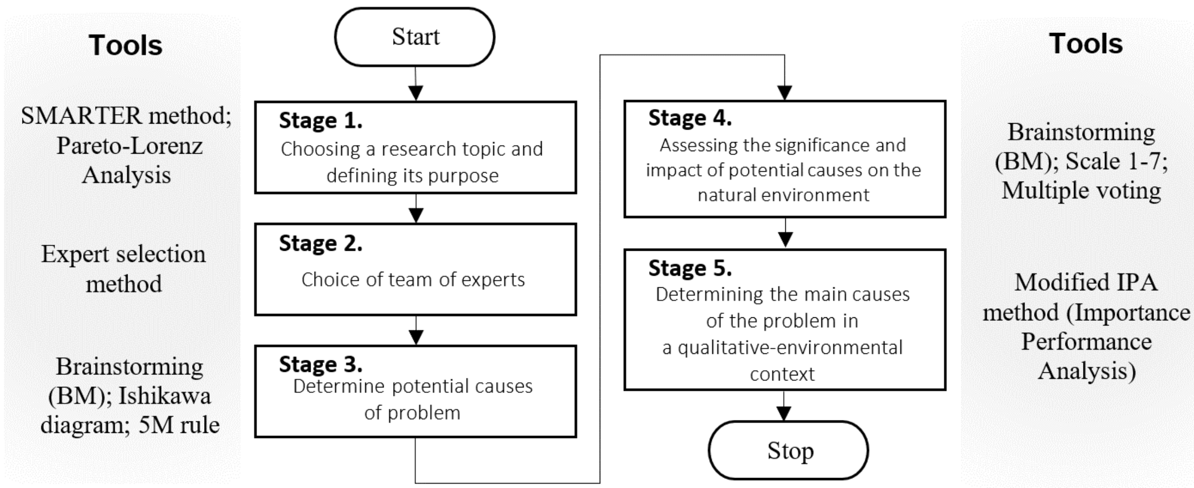

Fig.1. *Algorithm of Method supporting improving products in terms of qualitative-environmental.*

Stage 2. Choice of the team of experts. The proposed method should be performed with the participation of a selected team of experts, so that the members who will be responsible for achieving the purpose of the research. A team of experts is selected by the entity (expert) according to the competent members and their skills in dealing with the analyzed problem. The method that supports the choice of experts is shown in studies, e.g. [16,18].

Stage 3. Determine potential causes of the problem. A team of experts identified all potential causes, so causes which probably caused the problem. It is necessary to generate possibly the most possible causes. The tool supporting this process is brainstorming (BM) [58]. A leader of the team of experts should note all causes in a place visible to the team, e.g. table. Additionally, it is appropriate to visualize and group all potential causes according to the main causes. The Ishikawa diagram (causes-and-effect diagram) with the 5M rule (man, material, method, machine, and measure) is an effective tool for it [11].

Stage 4. Assessment of the degree of significance of potential causes and their impact on the natural environment. All potential causes of the problem should be assessed in view of: a) the degree of significance of these causes for the emergence of the problem, and b) the impact of causes on the natural environment. Assessments admit experts on a scale from 1 to 7, where 1 – the cause causes the problem to a negligible extent (or the cause has a negligible impact on the environment), 7 – the cause causes the problem to a very significant extent (or the cause has a very significant negative impact on the environment) [59]. Assessments can be given during brainstorming (BM) and multiple voting [60]. Assessments can be noted in the Ishikawa diagram or in the summary table of assessments.

Stage 5. Determining the main causes of the problem in a qualitative-environmental context. In the proposed approach, the main causes of the problem have a simultaneous important impact on the occurrence of the problem and on the natural environment. To determine these causes, it was assumed that the IPA diagram (Importance Performance Analysis) [61-63]. The traditional form of the IPA diagram was modified to combine the importance of causes and impact on the natural environment, as shown in Fig.2.

The diagram is created according to the assessments of potential causes. The potential causes in the area "concentrate here" are the main causes, i.e., causes that have a significant impact on the emergence of the problem and simultaneously a significant impact on the natural environment. For the main causes, improvement actions should be proposed in the first place, i.e., those that will ensure the improvement of product quality and minimize the negative impact on the natural environment. This is the last step of the proposed method.

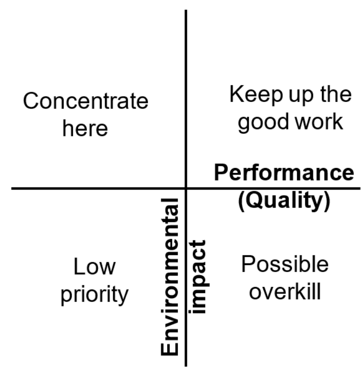

Fig.2. *Modified IPA diagram to qualitative-environmental analysis. Own study based on [26].*

Results

Test of the proposed method performed based on the incompatibility of the porosity cluster on the mechanical seal of the 410 alloy. Incompatibility was identified in a service-production enterprise localized in Poland. The test was carried out according to developed algorithm, i.e., in the five main stages.

Firstly, the study of research was selected and then the purpose of the research was determined. The subject of the research was selected by the entity (expert) according to the catalogue of the incompatibilities of products. One of the most frequent incompatibilities was the porosity cluster in the mechanical seal. This incompatibility was identified after non-destructive testing (NDT), i.e. fluorescent method (FPI). An example of incompatibility is shown in Fig.3.

Subsequently, the purpose of the research was defined according to the selected research subject. The goal was defined by the entity (an expert) using the SMARTER method. The purpose was to identify the main causes of the cluster of porosity on the mechanical seal from 410 alloy, where these causes will have the largest impact on the occurrence the of incompatibility, and simultaneously will have the most negative impact on the natural environment.

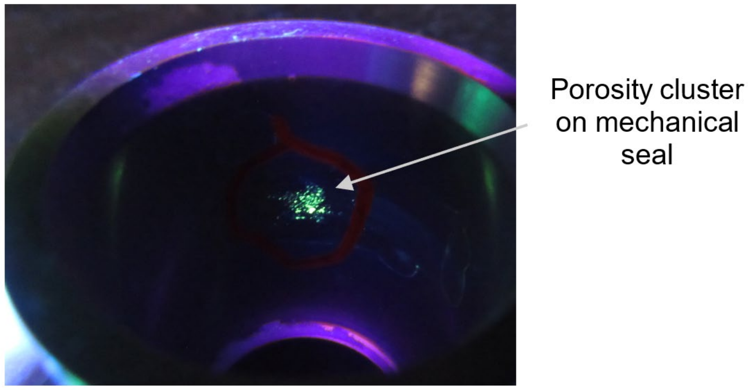

Fig.3. *Example of porosity cluster on mechanical seal.*

Then, the team of experts was selected. The team consisted of the authors of the article and the product quality control manager. A team of experts realized other stages of the method. Later, the team determined the possible causes of the porosity cluster. The causes generated during brainstorming (BM) and then noted on the Ishikawa diagram with the 5M rule (man, material, method, machine, and measure). The result of this stage is shown in Fig.4.

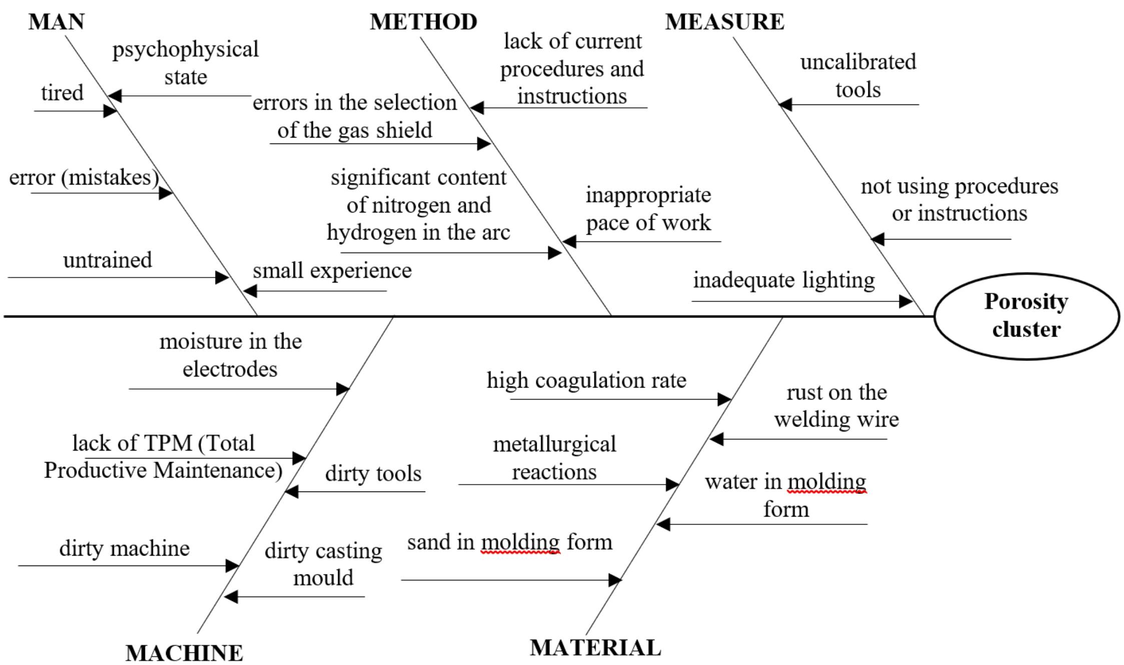

Fig.4. *Ishikawa diagram for problem of porosity cluster on the mechanical seal.*

***Table 1.** Assessments of the degree of importance of the potential causes and their impact on the natural environment.*

No.	Potential causes	assessment of the degree of influence of the potential cause on	
		the emergence of the problem	the natural environment
C1	tired	2	1
C2	error (mistakes)	3	1
C3	untrained	5	3
C4	psychophysical state	5	3
C5	small experience	4	5
C6	significant content of nitrogen and hydrogen in the arc	7	7
C7	errors in the selection of the gas shield	2	2
C8	lack of current procedures and instructions	1	2
C9	inappropriate pace of work	1	2
C10	uncalibrated tools	1	1
C11	not using procedures or instructions	1	3
C12	inadequate lighting	1	4
C13	moisture in the electrodes	2	5
C14	lack of TPM (Total Productive Maintenance)	3	4
C15	dirty machine	2	5
C16	dirty tools	2	5
C17	dirty casting mould	2	5
C18	high coagulation rate	4	2
C19	metallurgical reactions	6	5
C20	sand in molding form	6	4
C21	rust on the welding wire	5	6
C22	water in molding form	2	3

Then, a team of experts assessed the degree of influence of the potential causes on the emergence of the porosity cluster and their impact on the natural environment. As assumed by the method, all potential causes from the Ishikawa diagram were assessed on a Likert scale from 1 to 7. Potential causes were assessed as part of the brainstorming method (BM) implemented among of team of experts. The results of this process are shown in Table 1.

In the last stage, the main causes of the porosity cluster in the mechanical seal were determined in the qualitative-environmental context. For this purpose, a modified IPA diagram was used, which included assessments of the degree of impact of potential causes on the occurrence of the problem and the natural environment, as in Fig.5.

It was shown that the main causes of porosity cluster are causes belonging to the area of "concentrate here". Therefore, the main causes in this case were as follows: C12 – inadequate lighting, C13 – moisture in the electrodes, C14 – lack of TPM (Total Productive Maintenance), C15 – dirty machine, C16 – dirty tools, and C17 – dirty casting mould. For these causes, improvement actions should be applied in the first place. These activities should aim at improving the quality of the product and, at the same time, at reducing the negative impact on the natural environment.

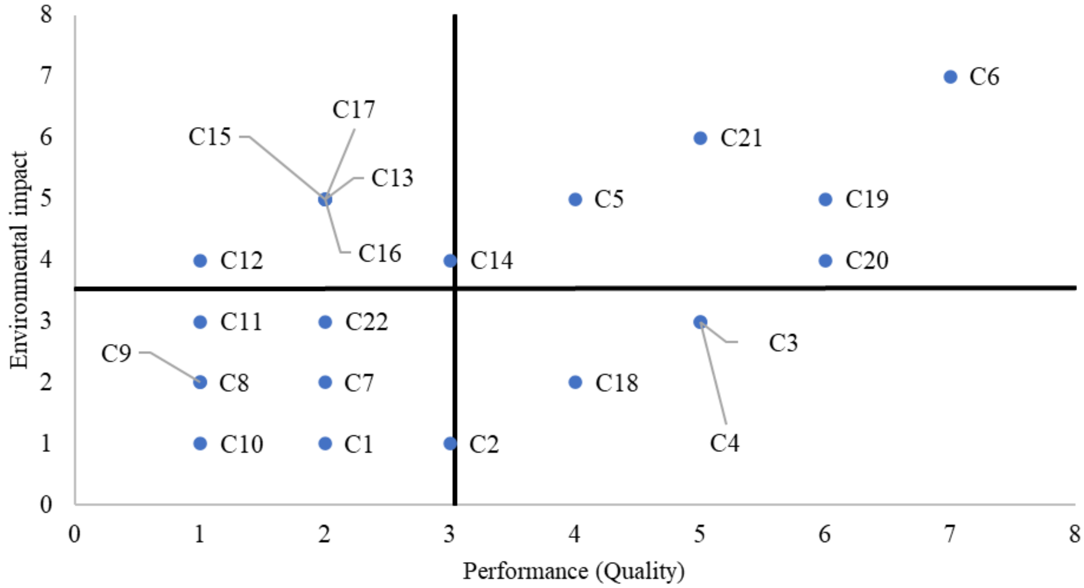

Fig.5. *Results from qualitative-environmental analysis on modified IPA diagram for the problem of porosity cluster.*

Summary

Changes in customers' expectations cause the need for continuous improvement of products. It is a complicated process, also in view of the need for environmental protection. Therefore, the objective of the article was to develop a method to analyze problems with the quality of products considering the impact on the natural environment. The method was developed by a coherent combination of selected techniques, i.e.: brainstorming (BM), Ishikawa diagram, 5M rule, multiple voting, seven-point Likert scale, and the IPA method. A method was carried out for mechanical seal of the 410 alloy, on which porosity cluster was detected. Initially, during the test of the method, the purpose of the research was determined, i.e.: identify the main causes of porosity cluster on the mechanical seal from 410 alloy, where these causes will have the largest impact on occurrence the of incompatibility and simultaneously will have the most negative impact on the natural environment. Then, a team of experts was selected, with whose participation an Ishikawa diagram was developed for the potential causes of this problem. Next, on a scale of 1-7 the degree of importance of potential causes in the porosity cluster and its impact on the natural environment. On the basis of these assessments, an IPA chart was developed, after which it was shown that the main causes of the porosity cluster were inadequate lighting, moisture in the electrodes, lack of TPM (Total Productive Maintenance), dirty machine, dirty tools, and dirty casting mould. For these causes, improvement actions should be applied in the first place. These activities should aim to improve the quality of the product and simultaneously reduce the negative impact on the natural environment. This method can be applied to any product and incompatibilities detected on them. Therefore, the method can be used in service-production enterprises to improve products in terms of qualitative-environmental.

References

[1] D. Siwiec, A. Pacana. Model Supporting Development Decisions by Considering Qualitative–Environmental Aspects, Sustainability 13 (2021) art. 9067. https://doi.org/10.3390/su13169067

[2] D. Siwiec, A. Pacana. A Pro-Environmental Method of Sample Size Determination to Predict the Quality Level of Products Considering Current Customers' Expectations, Sustainability 13 (2021) art. 5542. https://doi.org/10.3390/su13105542

[3] KC. Tan, XX. Shen. Integrating Kano's Model in the Planning Matrix of Quality Function Deployment, Total Quality Management 11 (2000) 1141-1151. https://doi.org/10.1080/095441200440395

[4] MF. Elmorshedy, MR. Elkadeem, KM. Kotb, IB. Taha, D. Mazzeo. Optimal Design and Energy Management of an Isolated Fully Renewable Energy System Integrating Batteries and Supercapacitors, Energy Convers. Manag. 245 (2021) art. 114584. https://doi.org/10.1016/j.enconman.2021.114584

[5] R. Wolniak. Downtime in the Automotive Industry Production Process – Cause Analysis, Quality Innovation Prosperity 23 (2019) art. 101. https://doi.org/10.12776/qip.v23i2.1259

[6] A. Naskar, S. Paul. Non-Destructive Measurement of Grinding-Induced Deformation-Depth Using Grazing Incidence X-Ray Diffraction Technique, NDT & E International 126 (2022) 102592. https://doi.org/10.1016/j.ndteint.2021.102592

[7] M. Brown, D. Wright, R. M'Saoubi, J. McGourlay, M. Wallis, A. Mantle, P. Crawforth, H. Ghadbeigi. Destructive and Non-Destructive Testing Methods for Characterization and Detection of Machining-Induced White Layer: A Review Paper, CIRP J. Manuf. Sci. Technol. 23 (2018) 39–53. https://doi.org/10.1016/j.cirpj.2018.10.001

[8] M. Ingaldi, R. Ulewicz. How to Make E-Commerce More Successful by Use of Kano's Model to Assess Customer Satisfaction in Terms of Sustainable Development, Sustainability 11 (2019) art. 4830. https://doi.org/10.3390/su11184830

[9] P. Jonšta, Z. Jonšta, S. Brožová, M. Ingaldi, J. Pietraszek, D. Klimecka-Tatar. The Effect of Rare Earth Metals Alloying on the Internal Quality of Industrially Produced Heavy Steel Forgings, Materials 14 (2021) art. 5160. https://doi.org/10.3390/ma14185160

[10] Ł. J. Orman, G. Majewski, N. Radek, J. Pietraszek. Analysis of Thermal Comfort in Intelligent and Traditional Buildings, Energies (Basel) 15 (2022) art. 6522. https://doi.org/10.3390/en15186522

[11] S. Ishikawa. The Gear Geometry of Tooth Engagement in Harmonic Drive, Proc. of the JSME Semi-International Symposium, Tokyo (1967) 94–104.

[12] L. Liliana. A New Model of Ishikawa Diagram for Quality Assessment, IOP Conf Ser Mater Sci Eng 161 (2016) 012099. https://doi.org/10.1088/1757-899X/161/1/012099

[13] D.D. Shinde, S. Ahirrao, R. Prasad. Fishbone Diagram: Application to Identify the Root Causes of Student-Staff Problems in Technical Education, Wireless Pers. Commun. 100 (2018) 653–664. https://doi.org/10.1007/s11277-018-5344-y

[14] R. Raman, Y. Basavaraj. Quality Improvement of Capacitors Through Fishbone and Pareto Techniques, Int. J. Recent Eng. Technol. 8 (2019) 2248-2252. https://doi.org/10.3940/ijrte.B2444.078219

[15] A. Hoła, M. Sawicki, M. Szóstak. Methodology of Classifying the Causes of Occupational Accidents Involving Construction Scaffolding Using Pareto-Lorenz Analysis, Applied Sciences 8 (2018) art. 48. https://doi.org/10.3390/app8010048

[16] A. Pacana, D. Siwiec. Universal Model to Support the Quality Improvement of Industrial Products, Materials 14 (2021) art. 7872. https://doi.org/10.3390/ma14247872

[17] D. Siwiec, A. Pacana. A New Model Supporting Stability Quality of Materials and Industrial Products, Materials 15 (2022) art. 4440. https://doi.org/10.3390/ma15134440

[18] A. Pacana, D. Siwiec. Method of Choice: A Fluorescent Penetrant Taking into Account Sustainability Criteria. Sustainability 12 (2020) art. 5854. https://doi.org/10.3390/su12145854

[19] Y. Yi, M. Yang, C. Fu, Y. Li. Gaming Strategies within a Green Supply Chain Considering Consumers' Concern about the Greenness and Conformance Quality of Products, Environ. Sci. Pollut. Res. 29 (2022) 69082–69100. https://doi.org/10.1007/s11356-022-20318-7

[20] G. Li, H. Wu, S. P. Sethi, X. Zhang. Contracting green product supply chains considering marketing efforts in the circular economy era, Int. J. Prod. Econ. 234 (2021) art. 108041. https://doi.org/10.1016/j.ijpe.2021.108041

[21] Z. Hong, X. Guo. Green Product Supply Chain Contracts Considering Environmental Responsibilities, Omega 83 (2019) 155-166. https://doi.org/10.1016/j.omega.2018.02.010

[22] S. Borkowski, R. Ulewicz, J. Selejdak, M. Konstanciak, D. Klimecka-Tatar. The use of 3x3 matrix to evaluation of ribbed wire manufacturing technology, METAL 2012 - 21st Int. Conf. Metallurgy and Materials (2012), Ostrava, Tanger 1722-1728.

[23] R. Ulewicz, F. Nový. Quality management systems in special processes, Transp. Res. Procedia 40 (2019) 113-118. https://doi.org/10.1016/j.trpro.2019.07.019

[24] T. Lipiński, R. Ulewicz. The effect of the impurities spaces on the quality of structural steel working at variable loads, Open Eng. 11 (2021) 233-238. https://doi.org/10.1515/eng-2021-0024

[25] R. Ulewicz, J. Selejdak, S. Borkowski, M. Jagusiak-Kocik. Process management in the cast iron foundry, METAL 2013 - 22nd Int. Conf. Metallurgy and Materials (2013), Ostrava, Tanger 1926-1931.

[26] R. Ulewicz, D. Jelonek, M. Mazur. Implementation of logic flow in planning and production control, Management and Production Engineering Review 7 (2016) 89-94. https://doi.org/10.1515/mper-2016-0010

[27] N. Baryshnikova et al. Management approach on food export expansion in the conditions of limited internal demand, Pol. J. Manag. Stud. 21 (2020) 101-114. https://doi.org/10.17512/pjms.2020.21.2.08

[28] R. Ulewicz, M. Ulewicz. Problems in the Implementation of the Lean Concept in the Construction Industries, LNCE 47 (2020) 495-500. https://doi.org/10.1007/978-3-030-27011-7_63

[29] N. Radek et al. Technology and application of anti-graffiti coating systems for rolling stock, METAL 2019 28th Int. Conf. Metall. Mater. (2019) 1127-1132. ISBN 978-8087294925

[30] N. Radek et al. Influence of laser texturing on tribological properties of DLC coatings, Prod. Eng. Arch. 27 (2021) 119-123. https://doi.org/10.30657/pea.2021.27.15

[31] G. Filo, E. Lisowski, M. Domagała, J. Fabiś-Domagała, H. Momeni. Modelling of pressure pulse generator with the use of a flow control valve and a fuzzy logic controller, AIP Conf. Proc. 2029 (2018) art.20015. https://doi.org/10.1063/1.5066477

[32] G. Barucca et al. The potential of Λ and Ξ- studies with PANDA at FAIR, Europ. Phys. J. A 57 (2021) art.154 https://doi.org/10.1140/epja/s10050-021-00386-y

[33] M. Domagala et al. CFD Estimation of a Resistance Coefficient for an Egg-Shaped Geometric Dome, Appl. Sci. 12 (2022) art.10780. https://doi.org/10.3390/app122110780

[34] N. Radek et al. The influence of plasma cutting parameters on the geometric structure of cut surfaces, Mater. Res. Proc. 17 (2020) 132-137. https://doi.org/10.21741/9781644901038-20

[35] M. Krynke et al. Maintenance management of large-size rolling bearings in heavy-duty machinery, Acta Montan. Slovaca 27 (2022) 327-341. https://doi.org/10.46544/AMS.v27i2.04

[36] P. Regulski, K.F. Abramek The application of neural networks for the life-cycle analysis of road and rail rolling stock during the operational phase, Technical Transactions 119 (2022) art. e2022002. https://doi.org/10.37705/TechTrans/e2022002

[37] M. Patek et al. Non-destructive testing of split sleeve welds by the ultrasonic TOFD method, Manuf. Technol. 14 (2014) 403-407. https://doi.org/10.21062/ujep/x.2014/a/1213-2489/MT/14/3/403

[38] I. Miletić, A. Ilić, R.R. Nikolić, R. Ulewicz, L. Ivanović, N. Sczygiol. Analysis of selected properties of welded joints of the HSLA Steels, Materials 13 (2020) art.1301. https://doi.org/10.3390/ma13061301

[39] N. Radek et al. Properties of Steel Welded with CO2 Laser, Lecture Notes in Mechanical Engineering (2020) 571-580. https://doi.org/10.1007/978-3-030-33146-7_65

[40] A. Deja et al. Analysis and assessment of environmental threats in maritime transport, Transp. Res. Procedia 55 (2021) 1073-1080. https://doi.org/10.1016/j.trpro.2021.07.078

[41] M. Scendo et al. Influence of laser treatment on the corrosive resistance of WC-Cu coating produced by electrospark deposition, Int. J. Electrochem. Sci. 8 (2013) 9264-9277.

[42] T. Lipinski, J. Pietraszek. Influence of animal slurry on carbon C35 steel with different microstructure at room temperature, Engineering for Rural Development 21 (2022) 344-350. https://doi.org/10.22616/ERDev.2022.21.TF115

[43] T. Lipiński, J. Pietraszek. Corrosion of the S235JR Carbon Steel after Normalizing and Overheating Annealing in 2.5% Sulphuric Acid at Room Temperature, Mater. Res. Proc. 24 (2022) 102-108.

[44] E. Skrzypczak-Pietraszek, J. Pietraszek. Seasonal changes of flavonoid content in Melittis melissophyllum L. (Lamiaceae), Chem. Biodiv. 11 (2014) 562-570. https://doi.org/10.1002/cbdv.201300148

[45] E. Skrzypczak-Pietraszek et al. Enhanced accumulation of harpagide and 8-O-acetyl-harpagide in Melittis melissophyllum L. agitated shoot cultures analyzed by UPLC-MS/MS. PLoS ONE 13 (2018) art. e0202556. https://doi.org/10.1371/journal.pone.0202556

[46] R. Ulewicz et al. Fatigue strength of ductile iron in ultra-high cycle regime, Adv. Mater. Res. 874 (2014) 43-48. https://doi.org/10.4028/www.scientific.net/AMR.874.43

[47] S.T. Dziuba, M. Ingaldi. Segragation and recycling of packaging waste by individual consumers in Poland, Int. Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 3 (2015) 545-552.

[48] J. Pietraszek, A. Szczotok, N. Radek. The fixed-effects analysis of the relation between SDAS and carbides for the airfoil blade traces. Archives of Metallurgy and Materials 62 (2017) 235-239. https://doi.org/10.1515/amm-2017-0035

[49] J. Pietraszek, N. Radek, A.V. Goroshko. Challenges for the DOE methodology related to the introduction of Industry 4.0. Production Engineering Archives 26 (2020) 190-194. https://doi.org/10.30657/pea.2020.26.33

[50] B. Jasiewicz et al. Inter-observer and intra-observer reliability in the radiographic measurements of paediatric forefoot alignment, Foot Ankle Surg. 27 (2021) 371-376. https://doi.org/10.1016/j.fas.2020.04.015

[51] J. Pietraszek. The modified sequential-binary approach for fuzzy operations on correlated assessments, LNAI 7894 (2013) 353-364. https://doi.org/10.1007/978-3-642-38658-9_32

[52] J. Pietraszek et al. Non-parametric assessment of the uncertainty in the analysis of the airfoil blade traces, METAL 2017 26th Int. Conf. Metall. Mater. (2017) 1412-1418. ISBN 978-8087294796

[53] J. Pietraszek et al. A. Advantages and disadvantages of various uncertainty assessment methods in material and technological predictive models, World Congress in Comput. Mech. and ECCOMAS Congress 1000 (2021) 1-8. https://doi.org/10.23967/wccm-eccomas.2020.053

[54] J. Fabiś-Domagała, G. Filo, H. Momeni, M. Domagała. Instruments of identification of hydraulic components potential failures, MATEC Web of Conf. 183 (2018) art.03008. https://doi.org/10.1051/matecconf/201818303008

[55] K. Knop et al. Evaluating and Improving the Effectiveness of Visual Inspection of Products from the Automotive Industry, Lecture Notes in Mechanical Engineering (2019) 231-243. https://doi.org/10.1007/978-3-030-17269-5_17

[56] G. Filo, P. Lempa. Analysis of Neural Network Structure for Implementation of the Prescriptive Maintenance Strategy, Mater. Res. Proc. 24 (2022) 273-280. https://doi.org/10.21741/9781644902059-40

[57] A. Pacana et al., Study on improving the quality of stretch film by Shainin method, Przemysl Chemiczny, 93 (2014) 243-245. https://doi.org/10.12916/przemchem.2014.243

[58] V.L. Putman, P.B. Paulus. Brainstorming, Brainstorming Rules and Decision Making, J. Creat. Behav. 43 (2009) 29-40. https://doi.org/10.1002/j.2162-6057.2009.tb01304.x

[59] G.M. Sullivan, A.R. Artino. Analyzing and Interpreting Data From Likert-Type Scales, J. Grad. Med. Educ. 5 (2013) 541–542. https://doi.org/10.4300/JGME-5-4-18

[60] J.M. Crosson, G. Tsebelis. Multiple Vote Electoral Systems: A Remedy for Political Polarization, J. Eur. Public Policy 29 (2022) 932–952. https://doi.org/10.1080/13501763.2021.1901962

[61] A. Gazda et al. Study on improving the quality of stretch film by Taguchi method, Przemysl Chemiczny, 92 6(2013) 980-982.

[62] J.J. Choi, C.A. Boger Jr. Association Planners' Satisfaction: An Application of Importance-Performance Analysis, J. Convention & Exhibition Manag. 2 (2000) 113-129. https://doi.org/10.1300/J143v02n02_10

[63] BY. Kim, H. Oh. An Extended Application of Importance-Performance Analysis, J. Hosp. Leisure Mark. 9 (2001) 107-125. https://doi.org/10.1300/J150v09n03_08