

**USING THE FMEA METHOD AS A RESPONSE TO A CUSTOMER COMPLAINT:
A CASE STUDY**

**USANDO O MÉTODO FMEA COMO RESPOSTA A UMA RECLAMAÇÃO DE
CLIENTE: UM ESTUDO DE CASO**

**UTILIZAR EL MÉTODO FMEA COMO RESPUESTA A LA QUEJA DE UN
CLIENTE: UN ESTUDIO DE CASO**

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Abstract

One of the most popular quality management methods is FMEA (Failure mode and effects analysis), which is used to analyze the risk of defects in the product or process in order to eliminate them even before they occur. Its effective implementation reduces the costs of elimination of defects, which increase exponentially in subsequent processes of product implementation. FMEA is most often used where highly complex products are manufactured or where production is a multi-stage process and many departments are involved. The aim of the article was to use the PFMEA to assess the quality of window guides and to improve their quality. This analysis was carried out based on complaints of the main business partner and helped to indicate the main cause for the complaint, identify the corrective actions and check the effectiveness of the proposed corrective actions. The analysis helped avoid similar problems in related products produced on the same production line.

Key words: production engineering, mechanical engineering technology, quality management, FMEA, PFMEA

Resumo

Um dos métodos de gestão da qualidade mais populares é o FMEA (modo de falha e análise de efeitos), que é usado para analisar o risco de defeitos no produto ou processo a fim de eliminá-los antes mesmo que ocorram. Sua implementação efetiva reduz os custos de eliminação de defeitos, que aumentam exponencialmente nos processos subsequentes de implementação do produto. FMEA é mais frequentemente usado onde produtos altamente complexos são fabricados ou onde a produção é um processo de várias etapas e muitos departamentos estão envolvidos. O objetivo do artigo era usar o PFMEA para avaliar a qualidade das guias de janela e melhorar sua qualidade. Esta análise foi realizada com base nas reclamações do principal parceiro comercial e ajudou a indicar a causa principal da reclamação, identificar as ações corretivas e verificar a eficácia das ações corretivas propostas. A análise ajudou a evitar problemas semelhantes em produtos relacionados produzidos na mesma linha de produção.

Palavras-chaves: Engenharia da produção; Engenharia mecânica; Gestão da qualidade; FMEA; PFMEA

Resumen

Uno de los métodos de gestión de calidad más populares es FMEA (modo de falla y análisis de efectos), que se utiliza para analizar el riesgo de defectos en el producto o proceso para eliminarlos incluso antes de que ocurran. Su implementación efectiva reduce los costos de eliminación de defectos, que aumentan exponencialmente en los procesos posteriores de implementación del producto. El FMEA se utiliza con mayor frecuencia cuando se fabrican productos muy complejos o donde la producción es un proceso de varias etapas y muchos departamentos están involucrados. El objetivo del artículo era utilizar el PFMEA para evaluar la calidad de las guías de ventana y mejorar su calidad. Este análisis se llevó a cabo en base a las quejas del socio comercial principal y ayudó a indicar la causa principal de la queja, identificar las acciones correctivas y verificar la efectividad de las acciones correctivas propuestas. El análisis ayudó a evitar problemas similares en productos relacionados producidos en la misma línea de producción.

Palabras clave: ingeniería de producción, tecnología de ingeniería mecánica, gestión de calidad, FMEA, PFMEA

1. INTRODUCTION

Enterprises cannot lag behind in terms of the resources they have, the technologies they use, or the products they manufacture. The competition is looking for new solutions, and customer requirements are constantly changing. Technological progress leads to the development of new technologies, machines, equipment, and new better materials. Enterprises need to grow and improve in order to follow the rest of the world. Otherwise, they risk going out of business (Krynke et al., 2014; Kotus et al., 2013).

There is a close link between quality and improvement, which is expressed in the concept of Total Quality Management (TQM) which states that every time a way can be found to achieve higher quality of the production process at a lower cost. It is believed that a higher quality of the production process can and must be achieved by improving both internal and external quality. Addressing nonconformity and problems in internal processes leads to cost minimization, and is therefore the main objective in the improvement of the internal quality of the production process. The improvement of external quality is aimed at the external business partners, in order to increase their satisfaction, which in turn leads to a larger market share and thus to higher profits (Kardas et al., 2017; Pribulova et al., 2011).

With the emergence of TQM, new concepts were developed that have grown in importance over time, including Six Sigma, Lean Production, and Business Process Reengineering. In the literature on the evolution of quality management, there was a transition from quality towards excellence (Klefsjö et al., 2008). Therefore, enterprises are looking for new solutions, ways to improve, which will allow for continuous improvement.

Many tools can help improve production processes and the products manufactured during these processes. One of them is FMEA (Failure Mode and Effects Analysis). As analyses have shown, 3 out of 4 nonconformities in production and use can be prevented at the design stage. Analyses can be carried out for a product, individual subassemblies or structural elements of the product, and the entire technological process or any operation within the process. This method makes it possible to assess the consequences of potential or existing nonconformities and identify their causes and has a preventive effect by providing preventive or corrective solutions (Ulewicz et al., 2019; Klimecka-Tatar and Ingaldi, 2020; Panyukov et al., 2020).

The main objective of the FMEA method is to regularly identify individual product and/or process defects and to eliminate or minimize their effects. This can be achieved by establishing the causal relationships of potential product defects taking into account risk factors. This allows for continuous improvement of the product and/or process through regular analysis and making corrections to eliminate the causes of defects and improve product properties (Fabiś-Domagala J. et al., 2019a; Fabiś-Domagala J. et al., 2019b).

The aim of the article was to use the FMEA method, or its modified version PFMEA, to assess the quality of produced window guides to improve their quality. This analysis was carried out based on complaints submitted by the main business partner. The analysis made it possible to indicate the main cause for the complaint, identify the corrective actions, reduce the risk associated with it, and check the effectiveness of the proposed corrective actions. The analysis allowed for avoiding similar problems in related products, which are stamped during a similar process in the enterprise studied.

2. THEORETICAL FRAMEWORK

FMEA (Failure Mode and Effects Analysis) is also known by other names such as FMECA (Failure Mode and Criticality Analysis) and AMDEC (Analyse des Modes de Défaillance et de leurs Effets) and represent a method of regular prevention of defects. It allows for defining actions to minimize the risk of their occurrence (Yang et al., 2015; Czajkowska, 2015).

The method was developed in the mid-1960s during the development and preparation of the Apollo-Saturn space flight program by NASA. NASA's new projects concerned complex structures and required the design of reliable products that would meet all the requirements. No mistakes that would lead to unsuccessful flights (and, worse still, to enormous costs and danger for the astronauts) were acceptable. In the 1970s, it began to be used in the nuclear and then in the automotive industry. Nowadays, it has grown into the most popular and most frequently used method in all industrial sectors where customers require high-quality products and processes (Krejci, et al., 2019; Baynal et al., 2018; Najafpour et al., 2017; Ehman and Kifor, 2016; Knop, 2017)

The inspiration for the development of FMEA was the observation that about 75% of all errors occur in the production preparation phases. Their detectability is low and increases during final inspection and product use. The aim of the FMEA is to identify defects in detail and analyze all nonconformities that occur in a product or process. The effective

implementation of the method reduces the costs of elimination of defects, which increase exponentially in subsequent processes of product implementation (Su et al., 2014; Liu et al., 2015; Aized at al., 2020; Sotoodeh, 2020).

There are several modifications to the FMEA method. The first is the design FMEA called DFMEA for short. It is performed at the initial stage of the design and helps collect a lot of information about product weaknesses, which are often the cause of damage during product use. In this case, the criterion for the analysis is the functional properties during use of the whole product, its components, or parts. DFMEA is particularly recommended at the time of implementation of any innovations in companies such as products, materials, and technologies. It is also used for new applications of already existing products when there is a risk of danger to people and the surroundings in case of failure, and operation of the product in very difficult conditions (Ijesh et al., 2016; Dulaska et al., 2017; Chi et al., 2020).

There is also a process FMEA, abbreviated PFMEA. This analysis provides opportunities to identify factors that hinder the fulfillment of technological requirements or may negatively affect the organization of the production process. It is used already at the initial stage of the process design. The criterion for PFMEA analysis is the logistical or technological process flow during assembly and machining operations, procedures, and activities (Szkoda, 2012; Banduka et al., 2018; Banduka et al., 2016; Johnson and Khan, 2003; Mascia et al., 2020).

The analysis based on the FMEA method is carried out in three stages (Hamrol, 2017):

1. preparation,
2. conducting the analysis itself,
3. introduction and supervision of the preventive measures.

At the preparation stage, the objectives, functions, and scope of FMEA analysis are defined. A team consisting of representatives of departments interested in its results, e.g. construction office, production, quality, and customer service departments, is also appointed. Product users (recipients of the services) can be also included in the team. Furthermore, an expert in a specific field can be invited to join the team. The leader is responsible for the organization and managing the team's work (Hamrol, 2017; Lee et al., 2017).

The main part of the analysis is performed at the second stage of the FMEA project. It consists of the following phases (Hamrol, 2017):

- indication of failures (problems) that may become apparent during the use of the product or during the process,
- determination of the effects and causes of the failures (problems) identified earlier and the control and monitoring methods currently in use that allow the defects or problems to be detected,
- establishing the relationships between the failure, effect and cause,
- assignment of the numerical values (severity (S), probability (P) and detection (D)) to the above-defined relationships,
- calculation of risk priority number (RPN),
- evaluation of a critical risk priority number (RPN_q).

Indices S, P, D can take values from 1 to 10 (Table 1-3). The team often uses check sheets, Pareto analysis, and other tools for the initial analysis of these data. It is also based on warranty repair reports, inspections, and the experience of designers and production engineers. The team should evaluate numbers based on the reliability data of similar designs or the frequency of failures in the process or a similar process (Szkoda, 2012; Zammori and Gabbrielli, 2012).

Table 1
Severity (S) - interpretation [33]

Evaluation	Evaluation criterion	Description of the evaluation
1	Very small	A minor defect that has no real effect on the operation of the device or system. The customer is unlikely to notice the defect.
2, 3	Small	A small defect causing only slight customer dissatisfaction. The customer is likely to experience a slight deterioration in product quality.
4, 5, 6	Average	A defect that causes some customer dissatisfaction. The customer experiences discomfort or is upset by the defect, notices deterioration in work.
7, 8	Big	High degree of customer dissatisfaction caused by a significant failure of the product. The defect does not violate the operational safety of the product or administrative regulations.
9	Very big	High user dissatisfaction, very high repair costs due to the breakdown of the entire product or component.
10	Huge	The significance of the entire defect is very high, the defect may endanger the customer's safety or violate the law.

Source: Zymonik, Z., Hamrol, A., Grudowski, P. (2013). Zarządzanie jakością i bezpieczeństwem. Warszawa, PL: PWE

Tabela 2
Probability (P) - interpretation [33]

Evaluation	Coefficient of possibility of occurrence	Evaluation criterion
1	<1 per 106	Improbable
2	1 per 20000	Very unlikely
3	1 per 4000	Unlikely
4	1 per 1000	Very small probability
5	1 per 400	Small probability
6	1 per 80	Significant probability
7	1 per 40	Very significant probability
8	1 per 20	Repeatable
9	1 per 8	Almost inevitable
10	1 per 2	Inevitable

Source: Zymonik, Z., Hamrol, A., Grudowski, P. (2013). Zarządzanie jakością i bezpieczeństwem. Warszawa, PL: PWE

Table 3
Detection (D) - interpretation [33]

Evaluation	Evaluation criterion	Description of the evaluation
1, 2	Sure	It is very unlikely that the defect will not be fully detected before the product leaves the manufacturing process. Automatic control of 100% elements, installation of security are needed.
3, 4	Big chance	It is unlikely that the defect will not be detected before the operation is completed. The defect is evident here, a few defects may not be detected.
5, 6	Possible	The probability that the defect will not be detected before the operation is completed is average. Additionally, manual control is difficult.
6, 8	Unlikely	It is possible that the defect will not be fully detected. Subjective evaluation not possible in terms of random sampling.
9, 10	Very unlikely or impossible	It is very possible that the defect will not be fully detected. The point is not controlled. The entire defect is invisible.

Source: Zymonik, Z., Hamrol, A., Grudowski, P. (2013). Zarządzanie jakością i bezpieczeństwem. Warszawa, PL: PWE

The multiplication of the indices S, P, D yields the risk priority number. The product of the partial evaluations varies between 1 and 1000. The higher the rate, the greater the "criticality" or "risk" of the cause or failure (Hamrol, 2017; Lolli et al., 2015). The team also specifies the priority number RPN_q indicating the limit between critical and other failures. Critical failures are considered to be those with the numbers greater than a fixed limit number and for which preventive action should be taken (Szkoda, 2012).

In the third stage, preventive or corrective actions are defined. They are aimed to (Hamrol, 2017):

- eliminate and minimize the likelihood of failures,
- reduce the significance of a specific failure to a minimum,
- increase the probability of detection of a given failure.

First and foremost, the focus should be on preventing failures rather than on finding and correcting them. Each corrective action should be assigned a person responsible for the implementation. Deadlines should also be specified for the implementation of preventive measures (Łańcucki, 2001; Liu et al.2013).

3. METHODOLOGY

The research was conducted at the request of the managers of a company. The company manufactures metal parts for the automotive industry and home appliances using stamping technology. To meet the needs of its business partners, the company implemented an integrated management system based on ISO TS 16949 and ISO 9001.

Despite the use of the integrated management system, preparation of specific procedures, and strict control, there have been numerous complaints from the main business partner for some time. The complaints concerned the exceeding of length tolerance for the guide section from one hole to another (43 ± 0.02). In February, the complaint was repeated. To improve relations with the business partner, the company delivered the ordered products and scrapped those defective. However, the employees were unable to find the cause. The problem was difficult to detect because it occurred randomly. The standard production inspections every hour often failed to reveal any deviations, but there were faulty products between the individual inspections which could only be detected using 100% quality control.

The managers asked the authors for help in improving the quality of manufactured products. The authors were to choose a research method, but also participate in the analysis as members of a six-person research team.

The research was conducted on the basis of data obtained from the complaints of product: Motor Support Assy RH/ LH window guide. The data was from 2018 (main analysis) and 2019 (re-calculation of RPN). A six-person research team, including all authors and 2 people from the research enterprise, was created.

The paper presents an analysis of the problem using the PFMEA method. The analysis aimed to eliminate the problem in the product studied and in related products. The defect was

analyzed based on an external complaint received by the Quality Department from one of the customers.

At the beginning all defects were listed. Effects and causes of these defects were indicated. Next, severity (S), probability (P) and detection (D) were indicated according to Tables 1-3. On the basis of those three number, risk priority number for each defect was calculated. The critical number of RPNq was defined as 100. For defects with RPN over 100 corrective measures were proposed and implemented. After this implementation RPN was re-calculated to check if the corrective measures helped to improve the process.

In order to confirm the obtained results, the manufactured details were additionally controlled. The control was carried out by four different operators, concerned different product parameters. The results obtained by all operators were compared.

4. PRESENTATION AND DISCUSSION OF RESULTS

A PFMEA analysis was carried out for the Motor Support Assy RH/ LH window guide. The process of the production of window guides was adopted as a criterion of the analysis including all its stages (from the delivery of the raw material from which the guide is made to obtaining the finished product). Packaging products into cardboard boxes was also included. All activities were illustrated using the PFMEA sheet as shown in Table 4.

Table 4

A PFMEA analysis for the Motor Support Assy RH/ LH window guide

Stage	Defects analysed	Effects of the defects	S	Causes of defects	P	Control methods	D	RPN
Delivery of raw material	Incorrect width	Problems during production	6	Supplier	2	Constant/random	2	24
	Incorrect thickness		6		2		2	24
	Poor quality		6		2		2	24
Progressive stamping process	Form	Installation difficulties or infeasibility	4	Incorrect setting point/ axis misalignment	3	2 parts per hour checked by the operator; Twice a day, 2 parts should be checked by the Quality Department	4	48
	Shape (blue dots)		4	Incorrect order/ incorrect stamping	3		4	48
	Shape (yellow dots)		4	Worn die or stamp	3		4	48
	Identification		4	Incorrect	2		4	32

				sequence or axis alignment					
	Location Ø 0.2 AB		4	Worn die or stamp	3		4	48	
	Location Ø 0.2 AB		4		3		4	48	
	(2x) Ø 9.5 (+0+01)		4		3		4	48	
	4 (+0+0.5)		4	Incorrect setting point, incorrect order	2		4	32	
	Location Ø 0.4 ABC		4		2		4	32	
	Perpendicularity 0.1 J		4		2		4	32	
	Ø 7.1 (+0-0.5) (x3)		7		2		4	32	
	Ø5.5 (+0-0.2) (x3)		4		2		4	32	
	Location 0.4A		7		2		4	32	
	2.5 (+0.3-0) (x3)		4		2		4	32	
	3.5 (+/-0.2)		4		2		4	32	
	Dimension 43 (+/- 0.2)		7		Incorrect sequence or axis alignment	5		7	245
	Ø8 (+0+0.1)		7		Incorrect setting point/ axis misalignment	2		4	56
	Location Ø0.2 DEF		4	2			4	32	
	Location Ø0.2 DE		4	2			4	32	
	Screws		7	Incorrect identification mark/ human error	3		4	84	
	Additional force		4		3		4	48	
	Thread		4	Worn die or stamp	3		4	48	
Packaging	Poor identification	Loss of confidentiality	4	Lack of regularity in checking	2	Pre-shipment inspection	3	24	
	Incorrect packing	Damaged parts	4	Container for damaged goods/not the original layers	4		5	80	
	Incorrect packaging	Risk of reprocessing or changing packaging	4	No packing instruction at the workplace	2		3	24	

Source: own study

The team conducted the analysis in a problem-based way. They analyzed only selected areas (raw material supply, progressive stamping process, packaging). The scope of the analysis was defined based on the complaint from the customer. Then the failures, their effects and causes for the specified defects were indicated. Relationships between each other were established. The table columns S, P, D were filled. It is particularly noteworthy that the entire possible scale was not used for these indices. For S and D indices, a maximum value of 7 was assigned and for P the maximum was 5. Then the RPN indicator was calculated. The authors also defined the critical number of RPNq at 100 for each defect.

It turned out that only the priority number for dimension 43 (+/-0.2) exceeds the critical number RPNq by 145 units. For this reason, corrective actions were specified for this dimension, with a responsible person assigned and a deadline set for their implementation. The actions described were evaluated in the same way as before. The new RPN no longer exceeded the critical level of RPNq, which brought the expected results, i.e. reduction of the risk of recurrence of the defect of the analyzed product (Table 5).

Table 5

Extended PFMEA analysis for a selected defect

Defects analysed	Corrective measures	Responsible person and date of execution	Description	S	P	D	RPN
Dimension 43 (+/- 0.2)	Sensors notifying about the workpieces in the chutes	Tool room, 26/10/2019	The use of material flow sensors in chutes	7	4	3	84

Source: own study

Based on the PFMEA analysis, aimed to avoid such problems in related products stamped during a similar process, the team introduced corrective actions. The tool room staff were assigned the task of installation of sensors notifying about the accumulation of workpieces in the chutes. The sensors were designed to stop the machine and thus the entire production process when the parts jammed against the chute and were deformed.

Four operators were designated to check each stamped part for one month for dimensions included in the PFMEA by means of a gauge and record the results in an inspection record. Other dimensions of the workpiece were also analyzed. Tables 6 and 7 demonstrate that the sensors proved effective.

Table 6

Entry in the record from the last day of workpiece inspection

Parameters	Operator 1	Operator 2	Operator 3	Operator 4
Location Ø 0.2 AB	OK	OK	OK	OK
Location Ø 0.2 AB	OK	OK	OK	OK
(2x) Ø 9.5 (+0+01)	OK	OK	OK	OK
4 (+0+0.5)	OK	OK	OK	OK
Location Ø 0.4 ABC	OK	OK	OK	OK
Perpendicularity 0.1 J	OK	OK	OK	OK
Ø 7.1 (+0-0.5)(x3)	OK	OK	OK	OK
Ø5.5 (+0-0.2)(x3)	OK	OK	OK	OK
Location 0.4A	OK	OK	OK	OK
2.5 (+0.3-0) (x3)	OK	OK	OK	OK
3.5(+/-0.2)	OK	OK	OK	OK
Dimension43 (+/- 0.2)	OK	OK	OK	OK
Ø8 (+0+0.1)	OK	OK	OK	OK
Location Ø 0.2 DEF	OK	OK	OK	OK
Location Ø0.2 DE	OK	OK	OK	OK

Source: own study

Table 7

Summary of records from the inspection record

Parts	Operator 1	Operator 2	Operator 3	Operator 4
inspected	4000	4332	4068	4264
defective	2	5	1	0
correct	3998	4327	4067	4264

Source: own study

The use of sensors proved to be a very effective way to eliminate the problem and yielded the expected results. The sensors enabled the operators to do their job properly, without having to constantly pay attention to whether the workpieces are transported from the press to the boxes correctly. There have been no new complaints about the window guides since the introduction of the solution.

5. CONCLUSION

The FMEA method is a very widely used quality management method. It is particularly effective in the analysis of complex products or processes. A single product, its subassembly, part of the process (e.g. single operation), and the entire technological process can be

analyzed using this analysis. The method is particularly useful at the design stage, where risks are assessed for design alternatives. The weaknesses of the entire process or product are evaluated and proposals for improvements are made. Particular emphasis is placed on the nonconformity and defects that occur most often or have the greatest impact on the entire process.

The article uses a modification of this method (PFMEA) to assess the quality of the window guides in order to improve their quality, and in particular to assess individual stages of these products. The analysis was performed due to the increased number of complaints from the main partner concerning this product. The main production problem was identified and then preventive measures were proposed to reduce the risks associated with this problem. Tool room employees were designated to install sensors to stop the machine when the parts jammed against the chute and were deformed.

It can be stated that the proposed corrective actions improved the quality of the window guides, but also improved the quality of other products manufactured on this production line. This was indicated by the RPNq level and the results of an inspection by four operators.

It should be noted that the correctly performed FMEA analysis and its complete documentation provide all evidence of the company's ability to provide services and manufacture products of high and stable quality. It should be stressed, however, that FMEA is a tool that should not be expected to generate ready-made solutions on how to eliminate the causes of defects. It gives an indication as to which places in the product, construction, or process are critical and why this is the case.

Improving the quality of supplied products has a positive effect on any company. Relationships with customers affect the resulting costs. Every external complaint involves a huge financial outlay: sorting already manufactured goods to find other defective parts or stopping production in the worst case are only some examples of such problems. The documented problem solving makes the supplier a reliable partner for the recipients to cooperate with.

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REFERENCES

- Aized, T., Ahmad, M., Jamal, M.H., Mahmood, A., Rehman, S.U.U., Srari, J.S. (2020). Automotive leaf spring design and manufacturing process improvement using failure mode and effects analysis (FMEA). *International Journal Of Engineering Business Management*, 12, Art. No 1847979020942438, doi: 10.1177/1847979020942438.
- Banduka, N., Tadic, D., Macuzic, I., Crnjac, M. (2018). Extended process failure mode and effect analysis (PFMEA) for the automotive industry: The FSQC-PFMEA. *Advances In Production Engineering & Management*, 13(2), 206-215, doi: 10.14743/apem2018.2.285.
- Banduka, N., Veža, I., Bilić, B. (2016). An integrated lean approach to process failure mode and effect analysis (PFMEA): A case study from automotive industry. *Advances in Production Engineering & Management*, 11(4), 355-365, doi: 10.14743/apem2016.4.233.
- Baynal, K., Sarı, T., Akpınar, B. (2018). Risk management in automotive manufacturing process based on FMEA and grey relational analysis: A case study. *Advances in Production Engineering & Management*, 13(1), 69-80, doi: 10.14743/apem2018.1.274.
- Chi, C.F., Sigmund, D., Astarci, M.O. (2020). Classification Scheme for Root Cause and Failure Modes and Effects Analysis (FMEA) of Passenger Vehicle Recalls. *Reliability Engineering & System Safety*, 200, Art No 106929, doi: 10.1016/j.res.2020.106929.
- Czajkowska, A. Identification and analysis of non-conformities in production of construction materials with the example of hot-rolled sheet metal. (2015). In: 24th International Conference on Metallurgy and Materials (METAL 2015), Brno, Czech Rep., 2015, Tanager, Ostrava, 2015, 1878-1883.
- Dulska, A., Studnicki, A., Szajnar, J. (2017). Reinforcing cast iron with composite insert. *Archives Of Metallurgy And Materials*, 62(1), 355-357, doi: 10.1515/amm-2017-0054.
- Ehman, Z., Kifor, V.C. (2016). An Ontology to Support Semantic Management of FMEA Knowledge. *International Journal of Computers Communications & Control*, 11(4), 507-521, doi: 10.15837/ijccc.2016.4.1674.
- Fabiś-Domagała, J., Momeni, H., Domagała, M., Filo, G. (2019a). Matrix FMEA Analysis as a Preventive Method for Quality Design of Hydraulic Components. *System Safety: Human - Technical Facility - Environment*, 2019, 1(1), 684-691, doi: 10.2478/czoto-2019-0087.
- Fabiś-Domagała, J., Momeni, H., Domagała, M., Filo, G., Bikass, S., Lempa, P. (2019b). Matrix FMEA Analysis of the Flow Control Valve. *Conference Quality Production Improvement – CQPI*, 1(1), 590-595. doi: 10.2478/cqpi-2019-0079.
- Hamrol, A. (2017). *Zarządzanie i inżynieria jakości*. Warszawa, PL: Wydawnictwo Naukowe PWN.
- Johnson, K.G., Khan, M.K. (2003). A study into the use of the process failure mode and effects analysis (PFMEA) in the automotive industry in the UK. *Journal of Materials Processing Technology*, 139(1-3), 348-356, doi: 10.1016/S0924-0136(03)00542-9.
- Kardas, E., Brozova, S., Pustejovska, P., Jursova, S. (2017). The evaluation of efficiency of the use of machine working time in the industrial company - case study. *Management Systems In Production Engineering*, 25(4), 241-245, doi: 10.1515/mspe-2017-0034.

- Klefsjö, B., Bergquist, B., Garvare, R. (2008) Quality management and business excellence, customers and stakeholders. Do we agree on what we are talking about, and does it matter?. *The TQM Journal*, 20(2), 120-129. doi: 10.1108/17542730810857354.
- Klimecka-Tatar, D., Ingaldi, M. (2020). How to Indicate the Areas for Improvement in Service Process - the Knowledge Management and Value Stream Mapping as the Crucial Elements of the Business Approach. *Revista Gestao & Tecnologia-Journal of Management and Technology*, 20(2), 52-74, doi: 10.20397/2177-6652/2020.v20i2.1878.
- Knop, K. (2017). Analysis of Risk of Nonconformities and Applied Quality Inspection Methods in the Process of Aluminium Profiles Coating Based on FMEA Results. *Production Engineering Archives*, 16, 16-21, doi: 10.30657/pea.2017.16.04.
- Kotus, M., Holota, T., Paulicek, T., Petrik, M., Sklenar, M. (2013). Quality and Reliability of Manufacturing Process in Automation of Die-Casting. In: *Materials, Technologies and Quality Assurance*. Book Series: Advanced Materials Research, 801, 103-107.
- Krejci, L., Schindlerova, V., Bucko, M., Hlavaty, I., Mician, M. (2019). The Application of PFMEA for Roller Bearings Production. *Manufacturing Technology*, 19(3), 439-445, doi: 10.21062/ujep/310.2019/a/1213-2489/MT/19/3/439.
- Krynke, M., Knop, K., Mielczarek, K. (2014). An identification of variables that influences on the manufactured products quality. *Production Engineering Archives*, 4(3), 22-25, doi: 10.30657/pea.2014.04.06.
- Lee, H., Baik, J., Kim, R. (2017). Failure mode and effects analysis drastically reduced potential risks in clinical trial conduct. *Drug Design, Development and Therapy*, 11, 3035—3043, doi: 10.2147/DDDT.S145310.
- Lijesh, K., P., Muzakkir, S., M., Hirani, H. (2016). Failure Mode and Effect Analysis of Passive Magnetic Bering. *Engineering Failure Analysis*, 62, 1-20, doi: 10.1016/j.engfailanal.2015.11.033.
- Liu, H.-C., Liu, L., Liu, N. (2013). Risk evaluation approaches in failure mode and effects analysis: A literature review. *Expert systems with applications*, 40(2), 828-838, doi: 10.1016/j.eswa.2012.08.010.
- Liu, H.-C., You, J.-X., Ding, X.-F., Su, Q. (2015). Improving risk evaluation in FMEA with a hybrid multiple criteria decision making method, *International Journal of Quality & Reliability Management*, 32(7), 763-782, doi: 10.1108/IJQRM-10-2013-0169.
- Lolli, F., Ishizaka, A., Ishizaka, A., Gamberini, R., Rimini, B., Messori, M. (2015). FlowSort-GDSS - A novel group multi-criteria decision support system for sorting problems with application to FMEA. *Expert Systems With Applications*, 42(17-18), 6342-6349, doi: 10.1016/j.eswa.2015.04.028.
- Łańcucki, J. (2006). *Podstawy kompleksowego zarządzania jakością TQM*. Poznań, PL: Wydawnictwo Akademii Ekonomicznej w Poznaniu.
- Mascia, A., Cirafici, A.M., Bongiovanni, A., Colotti, G., Lacerra, G., Di Carlo, M., Digilio, F.A., Liguori, G.L., Lanati, A., Kisslinger, A. (2020). A failure mode and effect analysis (FMEA)-based approach for risk assessment of scientific processes in non-regulated research laboratories. *Accreditation And Quality Assurance*, DOI: 10.1007/s00769-020-01441-9.
- Najafpour, Z., Hasoumi, M., Behzadi, F., Mohamadi, E., Jafary, M., Saedi, M. (2017). reventing blood transfusion failures: FMEA, an effective assessment method. *BMC Health Services Research* 17, 453, doi:10.1186/s12913-017-2380-3.
- Panyukov, D., Kozlovsky, V., Klochkov, Y. (2020). Development and Research FMEA Expert Team Model. *International Journal Of Reliability Quality And Safety Engineering*, 27(5), SI, Art No 2040015, doi: 10.1142/S021853932040015X.

- Pribulova, A., Babic, J., Baricova, D. (2011). Influence of Hadfield's steel chemical composition on its mechanical properties. *Chemicke Listy*, 105, SI, S430-S432, suplement 4.
- Sotoodeh, K. (2020). Failure Mode and Effect Analysis (FMEA) of Pipeline Ball Valves in the Offshore Industry. *Journal Of Failure Analysis And Prevention*, 20(4), 1175-1183, doi: 10.1007/s11668-020-00924-8.
- Su, C.T., Lin, H.C., Teng, P.W., Yang, T.H. (2014). Improving the reliability of electronic paper display using FMEA and Taguchi methods: A case study. *Microelectronics Reliability*, 54(6-7), 1369-1377, doi: 10.1016/j.microrel.2014.02.015.
- Szkoda J.(2012). *Systemy zarządzania jakością w organizacjach*. Warszawa, PL: Instytut Transportu Samochodowego.
- Ulewicz, R., Mazur, M., Novy, F. (2019). The Impact of Lean Tools on the Level of Occupational Safety in Metals Foundries. In: 28th International Conference on Metallurgy and Materials (METAL 2019), Brno, Czech Rep., 2019, Tanger, Ostrava, 2019, 2013-2019.
- Yang, Cs., Zou, Yn., Lai, Ph., Jiang, N. (2015). Data mining-based methods for fault isolation with validated FMEA model ranking. *Applied Intelligence*, 43(4), 913-923, doi: 10.1007/s10489-015-0674-x.
- Zammori, F., Gabrielli, R. (2012). ANP/RPN: A multi criteria evaluation of the risk priority number. *Quality and Reliability Engineering International*, 28(1), 85-104, doi: 10.1002/qre.1217.
- Zymonik, Z., Hamrol, A., Grudowski, P. (2013). *Zarządzanie jakością i bezpieczeństwem*. Warszawa, PL: PWE.