THE APPLICATION OF THE FMEA METHOD TO FAILURE ANALYSIS IN THE PRODUCTION PROCESS IN A SELECTED COMPANY OF THE METALLURGICAL SECONDARY MANUFACTURING INDUSTRY

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Abstract

Failure modes and effects analysis (FMEA) is used by organizations to prevent and overcome the effects of defects that occur in the construction and manufacturing processes. Applying this method consists in studying all possible faults before approving of the construction solution. The final aim is the assessment of the risks associated with the planned production, construction and manufacturing. The aim of the article was the analysis of the failures, their causes and effects in the production process, in a selected company of the metallurgical secondary manufacturing industry, which deals with the production of metal architectural elements. The application of FMEA allowed to determine the importance of the faults and errors by point estimating, taking into consideration such criteria as: R - risk, I - importance of defects and D - detectability. The recommended corrective actions were indicated as a result of the conducted analysis.

Keywords: Failure modes and effects analysis - FMEA, risk, detectability, metallurgical secondary manufacturing industry, aluminum architectural elements

1. INTRODUCTION

The process of production logistics belongs to the group of the main processes and it is above the processes of purchasing, production and storage, because it is a chain of communication links between them. Production is not the use of machines and tools for processing materials, but the use of logic to the process of work [1]. The ensuring of proper planning allows to fulfill customer needs in a fixed time and a rapid response to the threats to the realization of plans.

Metallurgy, which is the science of metals, includes, among other things, heat treatment, molding, metallography, and extractive metallurgy. The subject of study in metallurgy is the processing of metal ores until the final product. Along with the development of extractive metallurgy, the development of metal treatment and powder metallurgy took place [2]. Presently, the processes of metal extraction make up only a small percentage of the subjects of study in metallurgy, which focuses mainly on metal processing, that is the production of everyday objects.

In this branch it is important to assess the risks associated with the planned production, construction and manufacturing, as about 75 % of the failures result from irregularities in the preparation stage of production. The error detection in the initial phase is small, and about 80 % of the failures are detected in the phase of manufacture, and also during the operation [3]. A useful tool to prevent and overcome the effects of faults that occur in the construction and manufacturing processes is the FMEA method (Failure modes and effects analysis), which, in practice, allows to realize the qualitative approach of "zero defects" as well as the need of "continuous improvement" [4].

The aim of the article was the analysis of the failures, their causes and effects in the production process in a selected company of the metallurgical industry, which deals with the production of small architectural elements. The application of FMEA allowed to determine the importance of faults and errors by point estimating, taking into consideration such criteria as R - risk, I - importance of defects and D - detectability. The recommended corrective actions were indicated as a result of the conducted analysis.

2. THE CHARACTERISTICS OF THE SELECTED COMPANY

2.1. General characteristics of the production sector of the remaining metal wares (PKD 25.9)

The manufacturing activity within the PKD (Polish Classification of Activities) 25.9 section is understood as physical or chemical processing of resources, materials or semi-finished products into new products. Resources, materials or semi-finished products undergoing processing, and vital changes, modifications, renovations and reconstructions are also connected with the manufacturing activity. Units classified within this section are defined as industrial plants, works or factories, which make use of machines and mechanically powered devices [5] and those plants which process resources and materials into new products manually. In 2014 in the Polish REGON register there were 7 381 active operators in this industry, 1.2% fewer than the previous year (see **Figure 1**).

Figure 1 Changing of the number of active operators in the industry in the years 2009-2014 [5]

Active operators in the industry worked in all the 16 provinces. The three administrative regions with the largest number of active operators at that time were the Masovian district (21.7 % of all), the Silesian region (13.8 % of all) and the Lesser Poland province (9.3 % of all). The three most common legal forms were running an individual business (70.5 % of the operators), partnerships (13.6 % of the operators) and limited liability companies (12.4 % of the operators). The three most common forms of ownership were the ownership of domestic natural persons (90.9 % of the operators), the remaining private domestic ownership (3.9 % of the operators) and the foreign ownership (2.6 % of the operators). The two largest groups consisted of active operators, which employed from 0 to 9 (88.1 % of the operators) and from 10 to 49 (8.6 % of the operators) of the persons [5].

The two subgroups in the industry which got the largest net income in 2010 consisted of the largest operators, which mainly dealt with the production of metallic packaging (4.3 billion zlotys) and the production of the remaining ready-made metal items, not classified anywhere else (3.3 % billion zlotys) [6].

2.2. The activity of the FULCO system company

The subject of study was the FULCO system company which operates in the metallurgical secondary manufacturing industry, producing metal architectural items. The company belongs to the FULCO GROUP, which operates within the structures of the Fonon Company. The organization of the firm is shown in **Figure 2**.

Figure 2 Organizational structure of the Fonon Company [7]

The company owns an independent design department, which deals with both visual and technical design, which is preparing the structural designs, the production, the workshop documentation and the assembly documentation. The company performs ironwork, welding, metal treatment, wood painting and the final montage. Part of the work is subcontracted to the outside performers, e.g. laser cutting of steel, galvanizing and powder painting.

The firm realizes four independent business projects. The subject of study was the activity of the company in terms of the production of aluminum architectural elements.

3. THE APPLICATION OF THE FMEA METHOD IN ALUMINUM ELEMENTS PRODUCTION PROCESS

3.1. The essence of the method

FMEA was developed in the 1960s for the needs of the American Apollo space program. Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service [8]. The success of the method in NASA caused its rapid popularization, especially in motorization and aerospace. The essence of the FMEA method is the analysis of a possibility of the occurrence of a product failure, its causes and effects, as early as at the designing stage or at the stage of developing a technological process, in order to eliminate failure before the product is ready. The method is a tool employed by designers who want to minimize the loss caused by a low quality of products [9]. It allows to determine the hierarchy of failures and with the most serious failures it makes it possible to plan the preventive measures and determine their effectiveness [10]. The aim of FMEA is to introduce appropriate changes in a product or a production process at the designing stage, in order to avoid failure occurring in similar products or processes. It can also be used successfully in a production unit and in technological processes, as well as in services and administration [11]. There are numerous modifications of the method [12] and many applications described [13].

FMEA is used by organizations to prevent and overcome the effects of faults, which occur in construction and manufacturing processes. The final aim is the assessment of risk connected with the planned production, construction, and manufacturing [14, 15].

Tables 1, 2 and **3** present the criteria of the estimation of the R, I and D factors.

Table 1 The criteria of the assessment of the R factor

R	Risk (probability or frequency)	Description
1	Very small/ hardly perceptible	A very small probability of failure occurrence (less often than once in 6 years)
2	Low	A low probability of failure occurrence (once or twice in 6 years)
3	Medium	A medium probability of failure occurrence (once a year)
4	High	A high probability of failure occurrence (a few times in a year)

Table 2 The criteria of the assessment of the I factor

I	Importance of defects	Description
1	Lack of influence	Lack of the production stopping, lack of the influence on the quality of the product and the process of production.
2	Significant	Disruption of the production process without the necessity to stop the production, lack of influence on the safety of employees.
3	Serious	Production stopping and detecting failure. Low or medium danger for the employees or other persons.
4	Very serious	Permanent production stopping. Very high danger for the employees and high danger for other persons.

Table 3 The criteria of the assessment of the D factor

D	Detectability	Description
1	Very easy	A warning symptom. Automatic alarm
2	Average detectability	A warning symptom. Lack of automatic alarm
3	Small detectability	A warning symptom. Lack of automatic alarm
4	Low detectability	Lack of symptom detectability

Rate risk RPN is calculated as the product of these factors: RPN = R x I x D.

3.2. The FMEA analysis for the aluminum elements production process

In the FULCO system company in terms of the FMEA analysis the importance of defects was defined by means of point estimating and the following criteria: R - risk, I - importance of defects, D - detectability. The interpretation of the result of the product of the R, I and D factors was presented in **Table 4**.

Table 4 Interpretation of the results of the product of the R, I and D factors

RPN	Priority indicator	Description
≥1	Minimum	Usually omitted in the analysis
≥8	Medium	A need for a small change
≥27	Critical point	A necessary intervention and changes in the process/installation
64	Maximum	Conducting a safe production is impossible

The analysis for the aluminum elements production process, the estimation of potential risk and the results of the verification and optimization of the solutions are presented in **Table 5**.

Table 5 The FMEA analysis of the aluminum elements production process

Failur	Operation	Kind of failure	Effects of failure	Causes of failure	Undertaken control measures	I	R	D	RPN	Recommended corrective actions	Responsible	Results			
												I	R	D	RPN
1	Aluminum cutting	Imprecise material cutting	Lack of possibility of further material treatment	Instruction error	Random daily control	3	2	3	18	Developing a new cutting instruction	Technologist	1	1	3	3
				Incorrect measuring by an employee		4	4	2	32	Additional employee training	Production manager	2	2	2	8
				Too big material batch to be cut		4	3	2	24	Reduction of the cutting material batch	Production manager	2	1	2	4

2	Aluminum ironing	Incorrect shaping of rods	The need for repeating the operation	Rupture of the body of the press	Basic equipment maintenance	4	3	4	48	Cutting fuse installing	Technologist	2	2	1	4
				Incorrect parameter selection	Random control	4	2	3	24	Control after every parameter setting	Hydraulic press operator	1	1	2	2
3	Cutting of rods with a band-saw	Not sharp cutting of rods	Mismatching of the elements with the construction	Material wear	Weekly control	2	3	2	12	Additional maintenance of the saw elements	Equipment conservator	1	1	1	1
4	Bending of rods	Incorrect properties of material endurance	Danger for the product users	Improperly selected bending parameters	Random control	4	3	4	48	Additional employee training	Production manager	3	1	2	6
5	Detection	Incorrect dimensions or lack of holes	A need for making corrections	Incorrect functioning of the warning system	Monthly software update	2	4	4	32	Purchase of newer software	Production manager	1	2	1	2
6	Sandblasting	Lack of tightness of the equipment	Danger for employees	Material wear	Maintenance of security features	4	2	4	32	Installing additional housing	Production manager	1	2	2	4
7	Anodizing	Lack of aesthetics	Frequent complaints A need for additional operations	Incorrect chemical composition of substances	Random control of substances	3	3	2	18	Substance control at every delivery	Technologist	2	1	1	2
				Incorrectly prepared workplace	Weekly ordering of the workplace	2	4	3	24	Daily ordering of the workplace	Employee of the position	2	1	2	4
8	Welding	Lack of smelting	Danger for users, Frequent complaints	Lack of a proper distance between the edges of the welded material	Control of each welded element	4	3	4	48	Additional training and practice	Production manager	2	2	2	8

Figure 3 presents occurring failures in a sorted way. The values have been presented in the descending order, which allows to indicate the most critical problems.

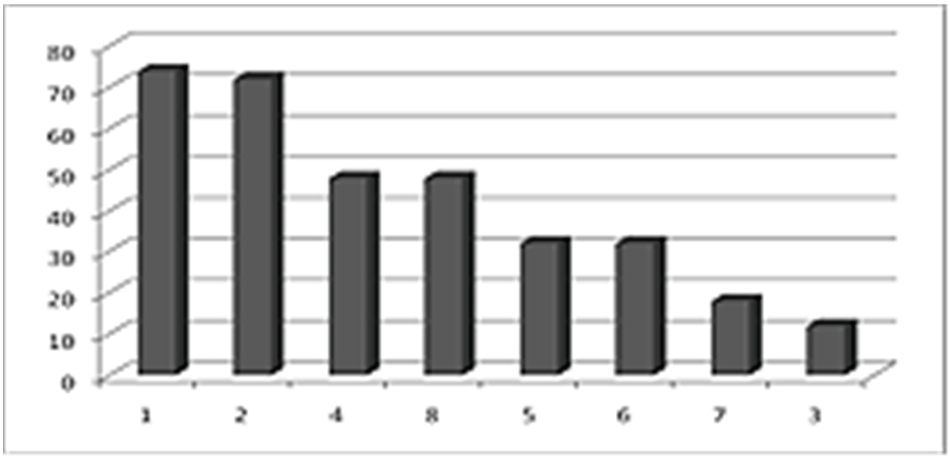

Figure 3 Failure diagram

In the FMEA analysis it has been assumed that the most serious failure is that whose risk rate (RPN) is higher than 27. On the basis of the above assumption 6 faults have been considered critical and they should be followed by introducing corrective actions. The faults include:

- imprecise material cutting,
- incorrect shaping of rods,
- incorrect properties of material endurance,
- lack of smelting,
- incorrect dimensions or lack of holes in rods,
- lack of tightness of the gritter.

Therefore, it is necessary to reduce the indicators of the failure to a minimum level or at least a medium level. As a result of the conducted analysis the company has started introducing the recommended corrective actions.

4. CONCLUSION

Since the 1990s FMEA has been used also as a tool for improving processes (not only productive ones) as well as a simple tool for market management. Despite the fact that over half of a century has passed since it was developed, FMEA still finds new applications. The method can be easily computerized and used in a semi-automatic mode with the use of the MRP/ERP systems.

In the subject of study, as a result of implementing FMEA, corrective actions have been proposed (as presented in **Table 5**). There are three possible directions of improvement: the reduction of probability, the improvement of failure detectability and the reduction of the importance of the effect. The choice depends on the complexity of the failure and on the product. The success is closely related to the experience and the competence of members of the team using the method. The presented example has been limited to a single product of a firm, in practice, the research should be extended. Given several dozens or several hundreds of potential faults, it is advisable to employ additionally the Pareto method, in order to differentiate the faults which should be dealt with first. As a result of the conducted analysis, the most serious faults have been pointed out. Further research should focus on minimizing the probability of the failure occurrence.

The early prevention of failure is especially important in the metallurgical secondary manufacturing industry. As the analyses show, three quarters of the faults occurring in the production and in the use can be prevented at the designing stage. Implementing the proposed corrective actions should allow the company to improve the production process of an analyzed product.

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REFERENCES

[1] DRUCKER, P. F. *Praktyka zarządzania*. Kraków: Wyd. Czytelnik. Nowoczesność. AE, 1994.

[2] *CHANG, I., ZHAO, Y.* (*Eds.*) **Advances in Powder Metallurgy**. Properties, Processing and Applications. Woodhead Publishing Series in Metals and Surface Engineering, 2013.

[3] URBANIAK, M. *Zarządzanie jakością. Teoria i praktyka.* Warszawa: Difin, 2004. 318 p.

[4] GOBLE, W. The FMEA method. *InTech*, 2012, vol. 59, no. 2, pp. 14-16.

[5] REJESTR REGON, Główny Urząd Statystyczny, status for 2014.

[6] MONITOR POLSKI B, data for 2010.

[7] Materials from FULCO system, http://fulcosystem.pl.

[8] TAGUE, N. R. *The Quality Toolbox*, Second Edition, ASQ Quality Press, 2004. pp. 236-240.

[9] WAWAK, S. *Programowanie rozwoju jakości wyrobu.* In *Metody planowania strategicznego na poziomie korporacji i w obszarach funkcjonalnych*. niepublikowane, Stabryła, A. (Ed.), Kraków: Akademia Ekonomiczna w Krakowie, 1999.

[10] CHEN, C-C. A developed autonomous preventive maintenance programme using RCA and FMEA. *International Journal of Production Research*, 2013, vol. 51, no. 18, p. 5404.

[11] VINODH, S., SANTHOSH, D. Application of FMEA to an automotive leaf spring manufacturing organization. *The TQM Journal*, 2012, vol. 24, no. 3, pp. 260-274.

[12] SNOOKE, N., PRICE, C. Automated FMEA based diagnostic symptom generation. *Advanced Engineering Informatics*, 2012, vol. 26, no. 4, pp. 870-888.

[13] ODLANICKA-POCZOBUTT, M., KULIŃSKA, E. Projekt restrukturyzacji parku maszynowego wybranej odlewni metali - analiza procesu wdrożenia. *Logistyka (Logistics)*, 2015, vol. 6, CD-ROM.

[14] AHMADZADEH, F., GOLSHANI ASL, A. Risk Prioritization Based on Health, Safety and Environmental Factors by Using Fuzzy FMEA. *International Journal of Mining, Metallurgy & Mechanical Engineering*, 2013, vol. 1, no. 4, pp. 233-237.

[15] BARENDS, D. M., OLDENHOF, M. T., VREDENBREGT, M. J., NAUTA, M. J. Risk analysis of analytical validations by probabilistic modification of FMEA. *Journal of Pharmaceutical and Biomedical Analysis*, 2012, vol. 64-65, pp. 82-86.