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Using cost-based mathematical model and principle 80/20 to improve decision making for risk priority at FMEA

Nikola Banduka
University of Split (PhD student, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića 32, Croatia, nbanduka@fesb.hr)
University of Kragujevac (PhD student, Faculty of Engineering, Sestre Janjić 6, Serbia, nikola.banduka90@gmail.com)

Ivica Veža
University of Split (Full Professor, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića 32, Croatia, iveza@fesb.hr)

Boženko Bilić
University of Split (Full Professor, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića 32, Croatia, bbilic@fesb.hr)

Ivan Mačužić
University of Kragujevac (Associate Professor, Faculty of Engineering, Sestre Janjić 6, Serbia, ivanm@kg.ac.rs)

Miroslav Radojičić
University of Kragujevac (Full Professor, Faculty of Technical Sciences, Svetog Save 65, Serbia, miroslav.radojicic@ftn.kg.ac.rs)

Abstract

Producing in quality is often hard and time-consuming job, with many risks and problems. One of these risks and problems can be defect (failure) appearance. These problems can be controlled with various tools, techniques, and methods. One of them frequently used in industry is Failure Mode and Effect Analysis wider known as FMEA. FMEA has both many advantages and also many disadvantages. One of these various disadvantages is that cost is not included into decision making during risk prioritization. Cost is one of very important factors during the risk evaluation phase, especially the external cost which can affect customer directly. Therefore, this research is mainly oriented to finding solution for integration of costs into traditional way of risk prioritization. Study is extension of previously conducted study by Banduka et al. (2016) with using of principle 80/20 to define risk prioritization by adding coefficient of product (which failure affects) value into traditional pattern for RPN. In this research, that new pattern for RPN was extended by new coefficient for profitability of corrections and new RPN_K was achieved. At last, comparation of previous state with traditional RPN and new RPN_K prioritization was presented.

Key words: *FMEA, Principle 80/20, Cost.*

1. INTRODUCTION

The turbulent market of nowadays pressures companies to respond on customer demands very fast, with right quality and acceptable price. This three factors (time, quality, and price) are in interaction in this case, so the ideal balance between them should be found for achieving customer's satisfaction. Producing in quality is often hard and time-consuming job, with many risks and problems. One of these risks and problems can be defect (failure) appearance. The recommendation of the author Stamatis [1] is that this kind of failures which can disturb reliable working mode of production system should be regulated with quality on source, rather with prevention than detection (correction). These problems can be controlled with various tools, techniques, and methods. One of them frequently used in industry is Failure Mode and Effect Analysis wider known as FMEA.

FMEA is qualitative failure mode analysis, but analysis of consequence which this failure causes, also. One of the main goals of this analysis is to identify and evaluate potential failures and find their causes in order to suggest improvement solutions for these failures. The final goal of this analysis is failure free production, improvement of safety and reliability, and of course customer satisfaction improvement. FMEA is provided to be a living document which means that it should constantly be upgraded with new data, especially after some changes on design or inside the production process.

FMEA has many advantages, but also many disadvantages. One of these various disadvantages is that cost is not included into decision making during the risk prioritization. Cost is one of very important factors during the risk evaluation phase, especially the external cost which can affect customer directly. According to Banduka, N. et al. [2] during the FMEA realization team have to percept immediately if the solution is profitable.

In this paper will be presented extended mathematical model for cost and profitability definition based on previous work of Banduka, N. et al. on PFMEA analysis with principle 80/20 [3]. The previous work was based on definition of the risk priority with product priority included. The product priority was included with an additional coefficient (K_{PV}) included in the traditional RPN pattern. This research will be mainly oriented to costs of failure and profitability of implemented solutions.

2. FMEA THEORETICAL BACKGROUND

First version of FMEA analysis was provided in 1949 for the USA military needs under the name military procedure MIL-P-1629, and that was the first documentation of this analysis at the same time [4]. This analysis in that time was used as a technique for failure mode definition in systems as also for consequences which this failure causes. FMEA realization concept was different from nowadays FMEA realization concept. First formal use of today known FMEA analysis was in 1965 for aerospace industry needs. Concretely, NASA used it for “Apollo” space project [4]. Later from 1965 this analysis was actively used for aero-space industry needs, but also for nuclear industry needs [5]. One decade later in early 1980s FMEA was applied for automotive industry need, first time by Ford Motors in 1973.

In nowadays FMEA in widely used and it can be said that FMEA has become standard practice in many companies all over the world [4]. Onodera [6] identified over 100 different application of FMEA in Japan in 1997. Many other authors highlighted wider application of FMEA in various industries. Some of them are: among the most common are automotive and aerospace industry [1, 4, 5, 7-10], military industry [1, 4, 8, 10, 11], electrical components production industry [4, 7, 9, 10], nuclear industry [1, 7, 8, 10], medicine and medical equipment production industry [1, 10-12]. In addition to the before mentioned application, use of FMEA is also present in: retail, mechanical, construction, chemical and service industries, in companies for hardware and software development, information systems, food production companies, plastic injection companies, in power plants, civil engineering, telecommunications, etc. [1, 4, 7-15].

FMEA is usually conducted with multidisciplinary team by fulfilment for predefined FMEA form (FMEA report). Traditional RPN (Risk priority number) indices are achieved by multiplying three different indices: Severity (S), Occurrence (O) and Detection (D), as it is presented in Equation (1). Usually, each of three indexes has the value from 1 to 10 on the predefined scale. According to this, RPN may go from 1 to 1000. There are examples where scale goes from 1 to 5, also [1]. According to the rule which probably was adopted from automotive industry, corrective actions are mandatory when RPN exceeds value 100 or any of each three indices exceeds value 8.

$$RPN = S * O * D \tag{1}$$

3. METHODOLOGY

Methodology used for this research is based on extension of previous used principle 80/20 in the research by Banduka, N. et al. [3]. The previous research is supported by additional traditional RPN mathematical model extension based on costs for risk prioritization. Combination of this principle 80/20 previous research and new mathematical model based on costs, gives a new extended risk priority number RPN_K with two additional coefficients K_{PV} (coefficient of product value) and K_{PC} (coefficient of profitability of correction). These two coefficients are integrated in Equation (2).

$$RPN_K = S * O * D * K_{PV} * K_{PC} \tag{2}$$

Methodology for achieving of this pattern will be explained in the following two subchapters.

2.1 Principle 80/20

Principle 80/20 shows how more benefits can be achieved with less investment (see Figure 1). But this does not mean that proportion must be 80/20. In most of cases it is, but not in all. The number even does not need to have 100 in sum.

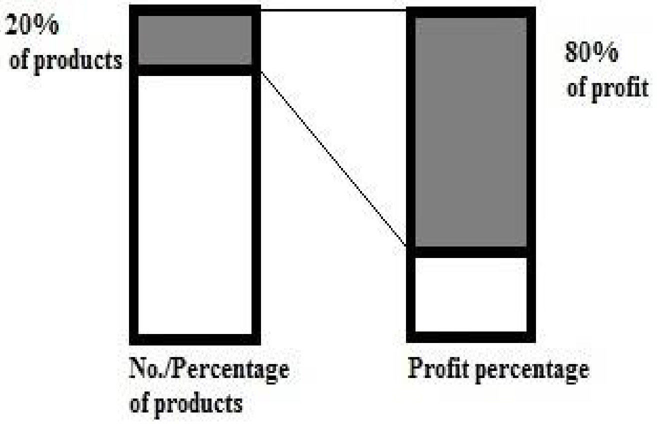

Figure 1. The ratio of 80/20 principle [3].

The precursor to principle 80/20 was discovered by the Italian economist Vilfredo Pareto in 1897. From that time this principle has had a lot of names, and some of them are: the Pareto principle, the Pareto rule, the rule 80/20, etc. After Pareto’s death this principle was forgotten until World War II. Many years later Harvard philology professor Zipf, G. K. [16] started to use Pareto rule again and he named it “Principle of least effort”. It is evident that this researcher, among other fields, applied this principle in industry. Another and maybe even more important scientist for this kind of research interests, Juran, J. M. [17] also used this principle just two years later. Juran was responsible for quality revolution from

1950s to 1990s. Opposite to Zipf, Juran was employed in industry as an industrial engineer. He used principle 80/20 as a principle for quality improvement, and called it “rule of important minority”.

Nowadays, this principle is very often used in everyday life. It can be used by any intelligent person, any organization, social group, company, etc. It is evident that principle 80/20 brought great discoveries in business and economy. It also brought many benefits to various companies as IBM, Apple, Lotus, Microsoft, etc.

There are two known applications of Pareto and FMEA which are similar to this approach, but very different in purpose and structure. The idea of using 80/20 principle to improve FMEA is in focusing on failures which occur at products which are more valuable for company than others. During the FMEA realization, a team is looking on products and failures as they are all the same, and priority are those with the highest RPN coefficient. That is an ideal case. But in practise, it is usually different. Value of failure also depends on the product value, and the product value depends on the amount of contribution or profit which it brings to the company. So, in ranking of RPN, value of the products should be included.

Why is this so important? In industry, it is not so simple to invest in everything that is needed. Top management is usually focused on direct return from investments. When failure occurs, it is normally to make prevention and correction which is time-consuming and requires some additional costs. So, principle 80/20 should point out in which products and failures is more profitable to invest in, and which are less important according to product profitability priority. For this purpose, a coefficient K_{PV} is invented which is included in traditional RPN (see Equation (3)) [3].

$$RPN = S * O * D * K_{PV} \tag{3}$$

K_{PV} is coefficient of product value, defined by 80/20 principle. K_{PV} may have two numerical values (1 or 2). The lower percentage of total products which gives bigger amount of profit gets value 2, while the higher percentage which gives less percentage of profit gets value 1.

2.2 **Mathematical model for costs at FMEA**

FMEA has many constraints usually related to human factor, conduction procedure and FMEA form. One of these constraints is cost. Costs which appear from failure and benefits achieved by application of solutions, are neither included in FMEA form, nor in conduction procedure.

This problem first highlighted Gilchrist in 1993 [18]. Gilchrist proposed mathematical model for costs in FMEA based on probability. He proposed three different scenarios for this mathematical model, also. In Gilchrists model were presented some constraints. These constraints were solved by Ben-Daya, M. and Raouf, A. [19]. Braglia [20] included expected cost into risk prioritization and used AHP to rank weight of each index including the cost index. Kmenta, S. and Ishii, K. [21] proposed scenario-based FMEA based on cost of failure during the whole life cycle. Rhee, S. J. and Ishii, K. [22] proposed Life cost-based FMEA with few constraints and a year later they upgraded proposed constraints. They used empirical data and Monte Carlo simulation to improve reliability and serviceability at FMEA. Tarum, C. D. [23] proposed in construction of possible costs related to automotive industry, but only for decision making. He did not include costs into traditional RPN. D’Urso, G. et al. [24] proposed new risk priority indices with time and cost included. Dong, C. [25] used fuzzy utility theory for cost estimation. He also modified Gilchrists mathematical model. In his new calculation the expected cost is in increase when probability that failure will occur is in increase and probability that failure will be detected decreases. Chin, K. S. [26] developed expert system based on fuzzy FMEA. He included cost into decision making, also. Von Ahsen, A. [27] criticized Gilchrist model that it is impossible to include it into traditional RPN. She proposed a new mathematical model for cost estimation for FMEA. Hassan, A. et Al. [28, 29] proposed ABC (activity-based Costing) method for cost identification at cost-based FMEA. In later work they added QFD method, also. Carmignani, G. [30] proposed a new mathematical model for cost estimation. He changed traditional risk indices by new one, with new calculation formulas. He pondered these three indices by subjective opinion. Carmignani first proposed a mathematical model for improvement estimation and available budget for improvements. Vintr, Z. and Vintr, M. [31] proposed an approach for warranty cost assessment at FMEA. This study continued Dong’s previous work. Unlike Dong, they use available budget for improvements as Carmignani. Popović, V. et al. [32] included costs for decision making during the FMEA fulfilment related to traffic. Abdelgawad, M. and Fayek, A. R. [33] used quality, cost and time instead of S index. They used fuzzy and AHP for pondering and decision making, also. Zammori, F. and Gabbrielli, R. [34] integrated costs into S index using AHP and ANP. Lillie, E. et al. [35] used chart with scale from 1 to 5 to integrate cost in severity. They included implementation costs as well as return of the investment. Rezaee, M. J. et al. [36] used costs for decision making separately from RPN, for processing industry purpose. Tazi, N. et al. [37] used hybrid cost-FMEA approach for wind turbine reliability analysis.

After literature review for cost based FMEAs, it is confirmed that proposed method for modified RPN (see equation (2)) is not provided in literature. In many cases authors go deeply into details. In this case that is not important, because this method is decision making oriented. S, O, and D indices are same as for Traditional FMEA, but two additional coefficients are added.

The mathematical model for costs at FMEA is based on adding coefficient K_{PC} into traditional RPN pattern (see Equation (4)). K_{PC} is the coefficient for defining profitability of correction due to the failure appearance (see Equation (5)). This coefficient depends on two main values, C_F and V_{CF}. Where C_F presents a sum of the costs C_i (i=1…n, n is number of costs per failure) for one failure multiplied with number of failures which occur in one batch O_F (see Equation (6)). O_F is defined by dividing total quantity of batch Q_S with amount in which failure occur A (Equation (7)). O_F may have two different scenarios. The former is when A is adopted from Table 3, A_O is amount in which one failure occurs (see Equation (8)). The latter is when A is defined according to the previous available data in which one failure occurs - A_X (see Equation (9)). Cost of the failure is the same for S, O, and D. Another value for definition of K_{CP} is the value of the correction activity V_{CF} which is defined by the sum of all corrections V_{Ci} (i=1…n, n is the number of costs per failure) for one failure (see Equation (10)). When both costs and correction values are defined, coefficient K_{PC} ultimately has to be defined. K_{PC} may have two numerical values 1 or 2 (see Equations (11) and (12)).

$$RPN = S * O * D * K_{PC} \tag{4}$$

$$K_{PC} = \frac{C_F}{V_{CF}} \tag{5}$$

$$C_F = \sum_{i=1}^{n} C_i * O_F \tag{6}$$

$$O_F = \frac{Q_S}{A} \tag{7}$$

$$O_{FO} = \frac{Q_S}{A_O} \tag{8}$$

$$O_{FX} = \frac{Q_S}{A_X} \tag{9}$$

$$V_{CF} = \sum_{i=1}^{n} Vci \tag{10}$$

$$IF : K_{PC} > 1, then : K_{PC} = 2 \tag{11}$$

$$IF : K_{PC} < 1, then : K_{PC} = 1 \tag{12}$$

4. EXAMPLE

In order to show improvements and difference between traditional FMEA and improved cost-based FMEA 10 failures were taken arbitrary. First it will be presented traditional way of calculation, then K_{PV} and K_{PC} coefficients will be defined. With these two coefficients, new RPN_k will be defined and compared with traditional RPN. The traditional FMEA calculation for these 10 failures is presented in Table 1.

Table 1. Example of the traditional FMEA calculation [3].

Failure	S	O	D	RPN	The highest priority
F1	6	4	3	72	F8
F2	3	7	4	84	F10
F3	5	5	2	50	F2
F4	3	2	3	18	F9
F5	2	8	1	16	F1
F6	3	5	2	30	F3
F7	5	3	8	40	F7
F8	7	6	5	210	F6
F9	4	4	5	80	F4
F10	6	3	7	126	F5

First, K_{PV} coefficient is defined with using principle 80/20. In the Table 2 are shown 10 arbitrary used products (each product fits with each failure with a same number) with profit data which contribute to a company. For principle 80/20 calculation was used software extension for MS Excel – QI Macros 2016. In this case all failures belongs to different product. But in some other cases it is possible to have more then one failure for the same product. 80/20 chart (see Figure 2) is based on products by one side and profit data by the other side from Table 2.

Table 2. Data required for determination of K_{PV} [3].

Product	Profit (€)	Profit [%]
P1	5 780	1.307
P2	32 400	7.328
P3	37 000	8.369
P4	20 000	4.524
P5	6 950	1.572
P6	13 600	3.076
P7	68 900	15.584
P8	160 000	36.188
P9	19 000	4.297
P10	78 500	17.755
Total	442 130	100

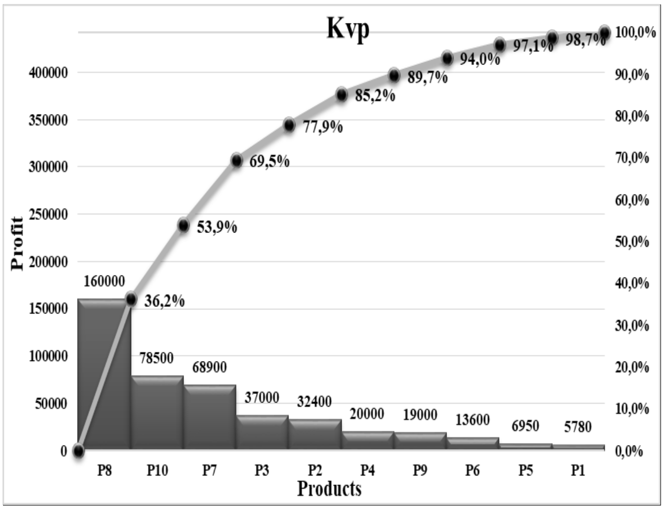

Figure 2. Determination of K_{PV} coefficient [3].

As it can be seen from the chart, from 3 products which is 30% of total products it is achieved almost 70% of the total profit of the company. So in this case is active principle 70/30. For products with 30% (P8, P10, and P7) of less is assigned 2 as value for K_{PV}, and for other products (P3, P2, P4, P9, P6, P5, and P1) value of K_{PV} is 1.

The second coefficient to define is K_{PC}. The elements required for K_{PC} determination are defined in the Table 3. These elements are: quantity of the batch (Q), amount of the failures per batch (A_O) adopted from Table 4, achieved number of failures which will occur in the batch (O_F), costs produced by the failure (C), total cost of the failure (C_f) and value of the correction activity V_{CF}. With all this data coefficient K_{PC} for all 10 failures was defined and adopted from Table 3.

Table 3. Determination of K_{PC} coefficient.

Failure	Q	A_O	O_F	C (€)	Cf (€)	V_{CF} (€)	K_{PC}	K_{PC} (1 or 2)
F1	27 000	10 000	2,7	20	54	248.14	0,22	1
F2	35 000	100	35	17	595	0.91	653,85	2
F3	112 000	2 000	56	56	3136	1	3136	2
F4	16 000	1 000 000	0,016	312	6,24	3700	0,0016	1
F5	180 560	50	3,61	109	393,49	0.18	2186,11	2
F6	68 000	2 000	34	30	1020	22009	0,046	1
F7	25 000	100 000	0,25	48	12	7896	0,0015	1
F8	37 000	500	0,074	215	15,05	11356	0,0013	1
F9	44 000	10 000	4,4	76	334,4	216.13	1,54	2
F10	93 000	100 000	0,93	7	6,51	395.69	0,0164	1

Table 4. Suggested FMEA table for Occurrence [38].

Likelihood of failure	Occurrence of cause	Rank
Very high	≥ 1 in 10	10
High	1 in 20	9
	1 in 50	8
	1 in 100	7
Moderate	1 in 500	6
	1 in 2 000	5
	1 in 10 000	4
Low	1 in 100 000	3
	1 in 1 000 000	2
Very low	Failure is eliminated through preventive control	1

After definition of both K_{PV} and K_{PC} coefficients, new risk priority number RPN_K can be calculated. Calculation of new RPN_K index is presented in Table 5. For calculation of RPN_K was used Equation (2) and new priority rank was set. Failures were arranged according to the highest RPN_K value.

Table 5. Calculation of the new RPN index

Failure	S	O	D	K_{PV}	K_{PC}	RPN_K	The highest priority
F1	6	4	3	2	1	144	F8
F2	3	7	4	1	2	168	F3
F3	5	5	2	2	2	200	F2
F4	3	2	3	1	1	18	F9
F5	2	8	1	1	2	36	F1
F6	3	5	2	1	1	30	F10
F7	5	1	8	1	1	40	F7
F8	7	6	5	2	1	420	F5
F9	4	4	5	1	2	160	F6
F10	6	3	7	1	1	126	F4

Comparation of the state achieved with traditional RPN index and the new state with cost-based FMEA is presented in Table 6. As it can be noticed from Table 6, five failures (F8, F2, F9, F1 and F7) kept their priority place, while other five failures (F10, F3, F6, F4 and F5) switched their places. Here is presented how new RPN_K index presents more reliable risk prioritization with both costs and product value included. Therefore with this new RPN_K the problem with costs can be avoided.

Table 6. Comparation of old state with new state.

RPN	Traditional RPN priority	RPN_K	New RPN_K priority
72	F8	144	F8
84	F10	168	F3
50	F2	200	F2
18	F9	18	F9
16	F1	36	F1
30	F3	30	F10
40	F7	40	F7
210	F6	420	F5
80	F4	160	F6
126	F5	126	F4

5. CONCLUSION

In this paper is presented extended research on previous research by Banduka, N. et al. [3]. Extension is done by adding a new coefficient K_{PC} with cost and benefit dimension. With this study are mainly solved problems of costs involvement into the FMEA.

This study has few constraints. In risk prioritization are included only costs and benefits, while safety and time factors are neglected. New RPN_K index goes from 1 to 4000 (because K_{PV} and K_{PC} indices go from 1 to 2) while improvement border stayed at 100. This can be constraint for some industries as automotive industry, which has standardized FMEA forms and procedures with traditional RPN, which goes from 1 to 1000. Multiplication of the traditional RPN with coefficients with value 1 and 2 is questionable, also.

The advantages of this study are mainly in improvement of risk priority reliability with involvement of costs and benefits, and value of the product.

Future work should be oriented to involvement of costs and benefits into severity index, rather than modifying existing RPN. Involvement of costs and profitability into FMEA should be overviewed by long term thinking, not just short term improvements [2]. There is space for development of special tables for cost into FMEA, also.

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6. REFERENCES

[1] Stamatis, D. H. (2003). *Failure mode and effect analysis: FMEA from theory to execution*, ASQ Quality Press, Milwaukee, Wisconsin, USA.

[2] Banduka, N., Veza, I. and Bilic, 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, Vol. 11, No. 4, 355-365.

[3] Banduka, N., Mačužić, I., Stojkić, Ž., Bošnjak, I. and Peronja, I. (2016). "*USING 80/20 PRINCIPLE TO IMPROVE DECISION MAKING AT PFMEA*", Annals of DAAAM & Proceedings, pp. 27.

[4] Pentti, H., & Atte, H. (2002). "*Failure mode and effects analysis of software-based automation systems*", VTT Industrial Systems*,* STUK-YTO-TR, pp.190.

[5] Korenko, M., Krocko, V., and Kaplík, P. (2012). *Use of FMEA method in manufacturing organization*, Journal of Manufacturing and Industrial Engineering, Vol. 11 No. 2, pp. 48-50.

[6] Onodera, K. (1997, January). "*Effective techniques of FMEA at each life-cycle stage*". In Reliability and Maintainability Symposium. 1997 Proceedings, Annual, IEEE, pp. 50-56

[7] Dinmohammadi, F. and Shafiee, M. (2013). *A fuzzy-FMEA risk assessment approach for offshore wind turbines,* International Journal of Prognostics and Health Management, Vol. 4, No.13, pp. 59-68.

[8] Breiing, A. J. and Kunz, A. M. (2002, April). "*Critical Consideration and Improvement of the FMEA*", In Proceedings of the TMCE*,* pp. 519-530.

[9] Deng, W. J., Chiu, C. C. and Tsai, C. H. (2007). *The Failure Mode and Effects Analysis Implementation for Laser Marking Process Improvement: A Case Study*, Asian Journal on Quality, Vol. 8, No.1, pp. 137-153.

[10] Liu, H. C., Liu, L. and Liu, N. (2013). *Risk evaluation approaches in failure mode and effects analysis: A literature review*, Expert systems with applications, Vol. 40, No.2, pp. 828-838.

[11] Rivera, S. S. and Mc Leod, J. E. N. (2009). "*Recommendations generated about a discontinuous distillation plant of biofuel*", In Proceedings of the World Congress on Engineering, Vol. 1, pp. 651-656.

[12] Reiling, J. G., Knutzen, B. L. and Stoecklein, M. (2003). *FMEA-the cure for medical errors,* Quality progress, Vol. 36, No. 8, pp. 67-71.

[13] Stålhane, T. and Wedde, K. J. (1998). *Modification of safety critical systems: an assessment of three approaches*. Microprocessors and Microsystems, Vol. 21, No. 10, pp. 611-619.

[14] Goddard, P. L. (2000). "Software FMEA techniques", In Reliability and Maintainability Symposium, 2000. Proceedings. Annual, IEEE, pp. 118-123

[15] Scipioni, A., Saccarola, G., Centazzo, A. and Arena, F. (2002). *FMEA methodology design, implementation and integration with HACCP system in a food company*, Food control, Vol. 13, No. 8, pp. 495-501.

[16] Zipf, G. K. (1950). *Human Behaviour and the Principle of Least Effort*, The Economic Journal, Vol. 60, No. 240, pp. 808-810.

[17] Juran, J. M. (1954). *Universals in management planning and controlling*, Management Review, Vol. 43*,* No. 11, pp. 748-761.

[18] Gilchrist, W. (1993). *Modelling failure modes and effects analysis*, International Journal of Quality & Reliability Management, Vol.10, No. 5, pp. 16-23.

[19] Ben-Daya, M. and Raouf, A. (1996). *A revised failure mode and effects analysis model*, International Journal of Quality & Reliability Management, Vol. 13, No. 1, pp. 43-47.

[20] Braglia, M. (2000). *MAFMA: multi-attribute failure mode analysis*, International Journal of Quality & Reliability Management, Vol. 17, No. 9, pp. 1017-1033.

[21] Kmenta, S. and Ishii, K. (2004). *Scenario-based failure modes and effects analysis using expected cost*, Journal of mechanical design, Vol. 126, No. 6, pp. 1027-1035.

[22] Rhee, S. J. and Ishii, K. (2003). Using cost based FMEA to enhance reliability and serviceability, Advanced Engineering Informatics, Vol. 17, No. 3, pp. 179-188.

[23] Tarum, C. D. (2001). *FMERA-failure modes, effects, and (financial) risk analysis,* SAE Technical Paper, (No. 2001-01-0375).

[24] D'Urso, G., Stancheris, D., Valsecchi, N., Maccarini, G. and Bugini, A. (2005). *"A new FMEA approach based on availability and costs",* In AMST'05 Advanced Manufacturing Systems and Technology, Springer, Vienna*,* pp. 703-712.

[25] Dong, C. (2007). *Failure mode and effects analysis based on fuzzy utility cost estimation*, International Journal of Quality & Reliability Management, Vol. 24, No. 9, pp. 958-971.

[26] Chin, K. S., Chan, A. and Yang, J. B. (2008). *Development of a fuzzy FMEA based product design system*, The International Journal of Advanced Manufacturing Technology, Vol. 36, No. 7-8, pp. 633-649.

[27] Von Ahsen, A. (2008). *Cost-oriented failure mode and effects analysis*, International Journal of Quality & Reliability Management, Vol. 25, No. 5, pp. 466-476.

[28] Hassan, A., Siadat, A., Dantan, J. Y. and Martin, P. (2009). *A quality/cost-based improvement approach for conceptual process planning*, International Journal of Management Science and Engineering Management, Vol. 4, No. 3, pp. 188-197.

[29] Hassan, A., Siadat, A., Dantan, J. Y. and Martin, P. (2010). *Conceptual process planning–an improvement approach using QFD, FMEA, and ABC methods*, Robotics and Computer-Integrated Manufacturing, Vol. 26, No. 4, pp. 392-401.

[30] Carmignani, G. (2009). *An integrated structural framework to cost-based FMECA: The priority-cost FMECA*, Reliability Engineering & System Safety, Vol. 94, No. 4, pp. 861-871.

[31] Vintr, Z. and Vintr, M. (2009, July). "*An application of FMEA for warranty cost assessment*", 8th International Conference on Reliability, Maintainability and Safety, IEEE, pp. 612-616

[32] Popović, V., Vasić, B. and Petrović, M. (2010). *The possibility for FMEA method improvement and its implementation into bus life cycle,* Strojniški vestnik-Journal of Mechanical Engineering, Vol. 56, No. 3, pp. 179-185.

[33] Abdelgawad, M. and Fayek, A. R. (2010). Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP, *Journal of Construction Engineering and Management*, *136*(9), 1028-1036.

[34] Zammori, F. and Gabbrielli, R. (2012). *ANP/RPN: A multi criteria evaluation of the risk priority number*, Quality and Reliability Engineering International, Vol. 28, No. 1, pp. 85-104.

[35] Lillie, E., Sandborn, P. and Humphrey, D. (2015). *Assessing the value of a lead-free solder control plan using cost-based FMEA*, Microelectronics Reliability, Vol. 55, No. 6, pp. 969-979.

[36] Rezaee, M. J., Salimi, A. and Yousefi, S. (2016*). Identifying and managing failures in stone processing industry using cost-based FMEA*, The International Journal of Advanced Manufacturing Technology, pp. 1-14.

[37] Tazi, N., Châtelet, E. and Bouzidi, Y. (2017). *Using a Hybrid Cost-FMEA Analysis for Wind Turbine Reliability Analysis*, Energies, Vol. 10, No. 3, pp. 276.

[38] Chrysler LLC, Ford Motor Company, General Motors Corporation (2008). "*POTENTIAL FAILURE MODE AND EFFECT ANALYSIS (FMEA)*", available at: http://www.engmatl.com/home/finish/20-engineering.../160-fmea-manual (accessed: 07. July 2017).