THE USAGE OF MCDM TECHNIQUES IN FAILURE MODE AND EFFECT ANALYSIS

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ABSTRACT

FMEA (Failure Mode and Effect Analysis) is an widely accepted risk assessment tool which used many of industries and has been subject of numerous scientific research. In this method, prioritization of failure modes based on RPN (Risk Priority Number) . Though FMEA is common accepted method, it has been criticized due to computation of RPN and prioritization of failure modes based on RPN scores. Some of these criticisms are, different combinations of O (Occurrence), S (Severity) and D (Detection) risk factors may exactly same value, relative importance among O,S and D is not taken into consideration and RPN is more sensitive to variations in O,S and D risk factors. To overcome the drawbacks of traditional RPN computation several approaches have been proposed in literature. Usage of MCDM (Multi Criteria Decision Making) techniques in prioritization of failure modes is one of these approaches. In this study, we purpose to obtain more proper results in prioritization of failure modes with use of AHP (Analytic Hierarchy Process) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) methods.

Key Words: Failure Mode and Effect Analysis, AHP, PROMETHEE, Risk Assessment

Jel Classification: M11

ÇOK KRİTERLİ KARAR VERME TEKNİKLERİNİN HATA MODU VE ETKİLERİ ANALİZİNDE KULLANIMI

ÖZET

Hata modu ve etkileri analizi (HMEA) bir çok sektörde kullanılan ve çok sayıda bilimsel araştırmaya konu olan geniş kabul görmüş bir risk değerlendirme metodudur. Bu metotta hata türlerinin önceliklendirilmesi "Risk Önceliği Göstergesi" (RÖG) değerine göre yapılmaktadır. Genel Kabul görmüş bir metot olmasına HMEA, RÖG hesaplamaları ve hata türlerinin RÖG değerlerine göre önceliklendirilmesi ile ilgili eleştirilere maruz kalmaktadır. Olasılık, şiddet ve keşfedilebilirlik değerlerinin farlı kombinasyonları ile aynı RÖG değerinin elde edilebilmesi, olasılık, şiddet ve keşfedilebilirlik faktörlerinin birbirlerine göre nispi ağılıklarının hesaplamalarda göz önünde bulundurulmaması ve olasılık, şiddet ve keşfedilebilirlik faktörlerinin değerlerinde yaşanan küçük değişimlerin RÖG değerini büyük oranda değiştirmesi eleştiri konularından bazılarıdır. Literatürde yöntemin eleştirildiği noktaların ortadan kaldırılması için kullanılan çok sayıda yaklaşım söz konusudur. Hata türlerinin önceliklendirilmesinde çok kriterli karar verme tekniklerinin kullanılması bu yaklaşımlardan biridir. Bu çalışmada hata türlerinin önceliklendirilmesinde çok kriterli karar verme tekniklerinden AHP ve PROMETHEE kullanılarak daha uygun sonuçların elde edilmesi amaçlanmıştır.

Anahtar Sözcükler: Hata Modu ve Etkileri Analizi, AHP, PROMETHEE, Risk Değerlendirme

Jel Kod: M11

Introduction

Due to the rapid developments in technology and increasing quality expectations, businesses that want to maintain their competitive power are required to tune up their quality, cost and production timing with the expectations of the customer (Chang, 2009). This fact increased the importance of the risk assessment techniques in production are all kinds of industries. There are numerous risk assessment techniques in the literature. One of the most widely accepted risk assessment technique is failure mode and effect analyses (Maheswaran and Loganathan, 2013). FMEA is a method that aims to prioritise and correct the failures or determine the kind of failures that should be prevented by identifying the probable types of failures that might arise in the products and planned processes. FMEA was first developed as an official design methodology in order to provide system security in NASA, and then in 1977 has been applied and developed by Ford motor. Currently, FMEA is product and process security analyse method that is used in a variety of sectors including automotive, nuclear energy and space researches (Kutlu and Ekmekçioğlu, 2012). Despite the fact that FMEA is a widely accepted technique, it was subjected to strong criticisms due to the calculation of the Risk Priority Number (RPN) that is used to sort the failure modes and prioritising the failure modes according to the RPN values. In order to resolve these criticisms, various techniques are used to calculate the RPN values and prioritise the failures. In this study, AHP and PROMETHEE the MCDM techniques were used in order to calculate the RPN values and prioritise the failure modes.

In the first part of this study, the criticisms directed to the theoretical structure and prioritising failure modes of FMEA were discussed. In the second part, a literature review was conducted about the theoretical structure, calculating RPN values and prioritising failure modes of FMEA, and studies that used related different techniques. In the third part, the methods used along with FMEA in this study were discussed. In the fourth part, the RPN values occurred in a factory producing shoe and shoe soles were calculated using FMEA, AHP and AHP-PROMETHEE methods and sorting of the failure modes of these methods. In the last chapter, the findings about the results and comparisons between the applied models were presented.

1. Failure Mode and Effect Analysis (FMEA)

FMEA is an analysis method that is used to evaluate the failure modes and aims to prevent them before they occur. In this method, questions such as "What might go wrong?" and "If something goes wrong, what would be the results?" are answered in order to determine the probable failures in the design stage and to prevent poor quality in the beginning. Besides, this method sheds light on the areas that needs to be improved during the process control by determining design and process characteristics (Sofyalıoğlu, 2011). Using FMEA application the effects of the failures related to the parts on the system performance is analysed, the system is improved, required changes are made and it is tried to make the system more reliable (Pillay and Wang, 2003). As distinct from the other risk assessment techniques that aim to determine the existing failures in a system, FMEA is rather a proactive approach that aims to determine the probable failures before they occur (Liu et al., 2012). In the FMEA applications, interdisciplinary application team formed by the experts from different operation functions determine the failure modes, calculates the risk level of each failure mode and prioritise the failures in order to apply convenient corrective and preventative operations. FMEA can be applied on the basis of a system, a subsystem, any product or process (Chin et al., 2009:).

Many failures might arise in a design, system, service and process that are different, have different effects and caused by different reasons. In such a situation, every failure mode should be evaluated and failures with high risk should be identified and prioritise (Wang et al., 2009). FMEA applications to determine and prioritise failure modes are effective failure prevention methodology that is used in many engineering and system security works. It has become a widely used risk assessment model because of its success in determining the potential failures in the products and processes, and in the operations correcting and preventing the failures (Tay and Lim, 2006). FMEA has found a wide range of application in production areas of the US, Japan and Europe (Chen and Lee, 2007). Despite the fact that four different kind of FMEA including system FMEA, service FMEA, design FMEA and process FMEA are recorded in the literature, in practice design FMEA and process FMEA are widely used and recognised in all branches of industry (Öztekin, 2006). Each failure mode is assessed according to three risk factors with a value changing between 1 and 10. These risk factors are described as severity (S), occurrence (O) and detectability (D). Severity is described as the degree of effect of a given failure on the system and customer. Occurrence is defined as the frequency of a given failure. Detectability is described as the identifiability of a given failure before it reaches and affects the customer. The values of these three risk factors are given in the (Figure 1) from positive to negative (Öztekin, 2006).

Occurence (O)	1 2 3 4 5 6 7 8 9 10 Nearly Impossible … Failure Almost Inevitable
Severity (S)	1 2 3 4 5 6 7 8 9 10 No Effect … Hazardous Effect
Detectability (D)	1 2 3 4 5 6 7 8 9 10 Almost Certain … Absolute Uncertainty

(Öztekin, 2006)

Figure 1: Risk Factor Values of the FMEA

The failure types with top priority are determined with sorting the RPN values that are obtained by multiplying the three risk factors given in (Table 1) (O x S x D = RPN) (Kutlu and Ekmekçioğlu, 2012). The fact that the failure types are prioritised according to their RPN values is being criticised by the scientist because of the following reasons:

- Although different O, S and D values have different effects on the failure risk, the multiplication of these values gives same RPN value. For example, when the values of O, S and D are 4,3,3 and 9,1,4 respectively, the RPN value for both case is found as 36 (Kutlu and Ekmekçioğlu, 2012: 1).
- The relative weights of the occurrence, severity and detectability factors are not taken into consideration in the calculations. In fact, in different cases, the risk factors might have different severity (Vencheh, et al. 2013).
- Because the RPN value is calculated by multiplying the risk factors, it is extremely sensitive to the small changes of the risk factors (Maheswaran and Loganathan, 2013). For example when the occurrence, severity and detection risk factors are 9, 9 and 10 respectively, the RPN value is found as 810; but when the occurrence, severity and detection risk factors are 9, 10 and 10 respectively, the RPN value becomes 900.

2. Literature; About The Methods Used With FMEA

The scientists have used various different methods in order to calculate the RPN vulaes and to sort the failure modes in order to compensate the above mentioned criticisms existing in the literature that are directed to the method. Some of the various RPN calculation and failure mode prioritisation methods are explained in this chapter. Braglia (2000) suggested a new failure mode and effect analysis method he called Multi Attribute Failure Mode Analysis (MAFMA). In the presented model, it was suggested to use the analytic hierarchy process (AHP) in order to prioritise the failure modes when various criteria, including intuitive, qualitative or quantitative ones are present. Pillay and Wang (2003) suggested two different approaches that include the application of fuzzy logic and gray theory together. The researchers applied fuzzy logic method to the failure modes found as a result of the evaluation of the team and calculated failure mode priorities. Chang (2009) suggested an approach in which ordered geometric averaging (OWGA) method is used for weighting the risk factor values and decision making trial and evaluation laboratory method (DEMATEL) for prioritising the failure modes in FMEA. Hu et al. (2009) obtained RPN values they called as green component and used fuzzy AHP method in order to prioritise failure modes that might increase the toxic content of the products. Chin at al. (2009) suggested a model that use data envelopment analysis and minimax regret rule if the different members of the FMEA team give different values for the risk factors.

Wang et al. (2009) used a fuzzy weighted geometric mean method which takes the relative weight of each risk factor when calculating RPN values of FMEA. Sofyalıoğlu (2011) presented a method based on the use of grey relationship model which enables to attain relative weight to the judgement factors in the prioritisation of the failure modes. Kutlu and Ekmekçioğlu (2012) presented an approach in which the failure modes are determined using fuzzy AHP method and prioritisations are made using fuzzy TIPSIS method. Liu at al. (2012) suggested a new approach in which risk factor weighting is determined using fuzzy logic and failure modes are determined using Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) method. Vencheh et al. (2013) suggested an approach based on the fuzzy linear programming model in which the risk factors of FMEA is determined based on fuzzy logic and RPN values calculated accordingly, and the maximum and minimum risk points are found using linear programming model, then the failure modes are prioritised according to the geometric mean of these values. Maheswaran and Loganathan. (2013), suggested an approach that used AHP and PROMETHEE methods together. According to this approach paired comparison of the risk factors are made, their weights are determined using AHP and failures modes are prioritised using PROMETHEE method and taking their weights into consideration.

3. Applied Methods

In this study, in order to compensate the limitations of FMEA and criticisms it was subjected, an method that used AHP and AHP-PROMETHEE methods together was used. In this method, first the failure modes and risk factors were determined and based on these values traditional RPN calculations were made. Then the FMEA team was asked to prioritise the failure modes according to the AHP scale and the weight of each failure mode was calculated by applying AHP to the resulting decision matrix. The weights of the failure modes were found using AHP and are multiplied with the RPN values of the failure modes in order to determine AHP-RPN values which in turn used to sort the failure modes. Finally weighting value of each failure mode was determined using AHP method, then final sorting order of the failure modes were found using normalized risk factor values with PROMETHEE method. The steps of the applied methods are presented in (Figure 2).

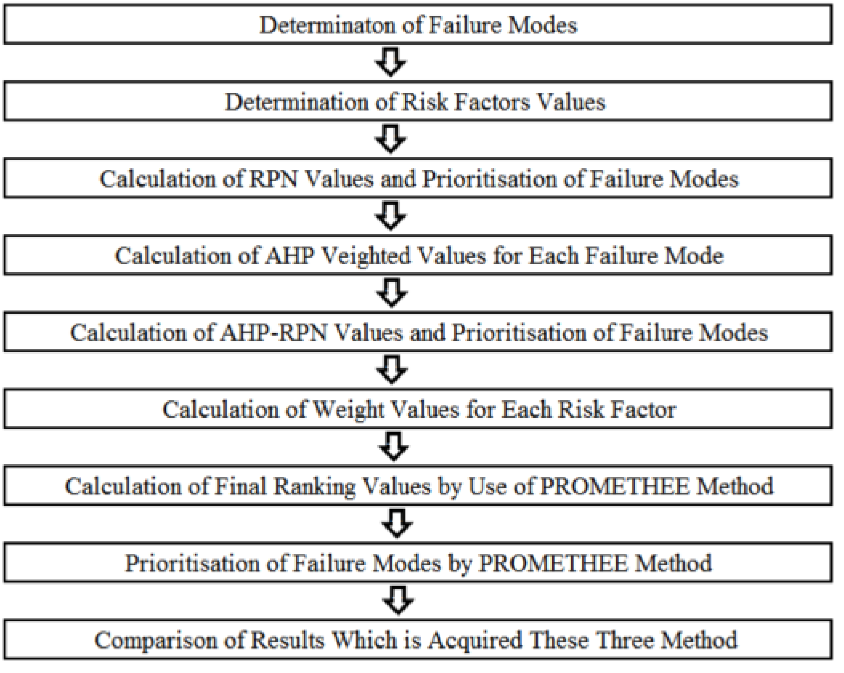

Figure 2. Steps of the Applied Methods

3.1. Analytical Hierarchy Process

Analytical hierarchy process (AHP) was developed by Thomas L. Saaty in the late 70ies. AHP is a multi-criteria decision making technique based on pairwise comparison. The multi-criteria decision making techniques are helpful approaches for the decision makers making it possible to take the effects of numerous independent factors into consideration (Ömürbek et al., 2013). The main advantage of the hierarchic structure of AHP is the fact that it enables to resolve the problem into its elements in detail and systematically, and to determine the relationships between the elements (Bruno et al. 2009). AHP enables to convert the data obtained from comparisons based on experiences into numeric data and evaluate them.

In the AHP method, first the alternatives and the criteria are determined, then based on the alternatives and the criteria a decision hierarchy is formed. In the next step pairwise comparison matrix is created and weight vectors of the criteria are determined. After calculating the degree of consistency, the priority values of the alternatives are obtained and the alternatives are sorted. When the consistency ratio is smaller than 0.10, it is accepted that the pairwise comparisons are valid (Saaty, 1980). The pairwise comparison of the alternatives determine according to the scale given in (Table-2).

Table 1. Saaty's Scale of AHP Relative Importance

Intensity	**Definition**
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

(Saaty, 1987)

3.2. Promethee Method

Promethee method is a multi-criteria decision making method developed by Brans in 1982 (Chen et al., 2011). Promethee method provides flexibility and facility at the same time and is a simpler sorting method for the multi-criteria analysis in terms of model and application compared to the other methodologies. The method presents both partial and total sorting of the alternatives, and also enables to make numerical or graphic sensitivity analysis (Yılmaz and Dağdeviren, 2010). Promethee method is suitable for the problems related to the sorting of limited alternatives to be evaluated according to numerous criteria (Chen et al., 2011). In the application of the method it is necessary to know the weight of each criterion and to determine preferred function (Taillandier and Stinckwich, 2011).

In the Promethee method, at first, weighting values of each criterion are calculated. Because, relative weights of alternatives take into consideration for calculating final ranking values in Promethee method. Weights values of criterion can determine using any method. In this study we use AHP method for determination of weighting values of risk factors. For this purpose FMEA team members made pairwise comparison of risk factors according to Saaty's AHP scale and weighting values calculated using AHP method. In the second step, the evaluation criteria are determined and a decision matrix is created and the data were normalized in order to determine the preferred function according to these data. The normalization formula is as below.

$$X' = X - \min(set) / \max(set) - \min(set) \qquad (1)$$

In the third step, preference function related to the evaluation factors are determined. Brans and Vincke presented six different types of preferred functions in order to enable the experts who will make the application within the context of the method to determine flexible standards (Chen et al. 2011). However, the preferred function presented by Vijay and Shankar (2010) was used in the FMEA model applied in this study, because these preferred functions were not suitable (Maheswaran and Loganathan, 2013).

$$P(x) = \left\{ \begin{matrix} 0 & x \leq t \\ x - t & x > t \end{matrix} \right\} \qquad (2)$$

In the fourth step, the paired comparisons of the alternatives were made taking the preferred functions into consideration, and aggregated preference functions are calculated by equation 3.

$$\pi(A, B) = \sum_{i=1}^{k} w_i p_i(A, B) \qquad (3)$$

In the fifth step, the following formulas are used in order to calculate entering flow and leaving flow values.

$$\emptyset^{+} = \frac{1}{n-1} \sum \pi(A, x) \qquad (4)$$

$$\emptyset^{-} = \frac{1}{n-1} \sum \pi(x, A) \qquad (5)$$

In the sixth step net outranking flow values are determined for each alternative by equation 6. In the last step all the alternatives are sorted according to their net outranking values. The alternative with the highest net outranking flow value is identified as the best alternative (Avikal et al. 2013).

$$\emptyset(A) = \emptyset^{+}(A) - \emptyset^{-}(A) \qquad (6)$$

4. Application

A shoe and shoe sole manufacturing factory which is located in İzmir, Turkey were selected for application of the proposed approach. Shoe sole production process were selected for this application among other processes in the factory. Major existing and potential failure modes, reasons and effects of failure modes in that process are determined by a group of experts. (Table 2) shows determined failure modes, risk factor values and RPN values of each failure modes.

Table 2. Failure Modes, Risk Factor and RPN Values

Process	Failure Modes	O	S	D	RPN
Shoe Sole Production Process	Difference in Raw Materials Lots (Colour Tone Problem)	1	7	6	42
	Holes on Shoe Sole	1	10	8	80
	Combustion of Raw Material	1	4	10	40
	Make Wrong Encolouring in Finishing	2	5	4	40
	Wrong Labelling	2	8	5	80

Firstly, we determined RPN values of each failure mode with traditional RPN calculating formula (O x S x D = RPN), secondly we used AHP method for calculating AHP-RPN values of failure modes and prioritized these failure modes by AHP-RPN values. In this approach we aimed computing weight values for each failure mode by AHP method and calculating AHP-RPN values. AHP-RPN values were acquired by multiplying weights with RPN value of each failure mode. Weighted values of failure modes are calculated by AHP methods. (Table 3) shows AHP weighted values, RPN values, AHP-RPN values of each failure mode and prioritized by AHP-RPN values of failure modes.

Table 3. AHP-RPN Values of Failure Modes

Failure Modes	AHP Weighted Values (CR=0,01)	RPN	AHP-RPN
Difference in Raw Material Lots (Colour Tone Problem)	0,089	42	3,74
Holes on Shoe Sole	0,445	80	35,6
Combustion of Raw Material	0,262	40	10,48
Make Wrong Encolouring in Finishing	0,052	40	2,08
Wrong Labelling	0,152	80	12,16

Thirdly, we prioritised failure modes by use of PROMETHEE method. In this method, at first, weights of risk factors were calculated by AHP method. Weights of Occurrence, Severity and Detectability risk factors are shown in (Table 4).

Table 4. Weight Values of Risk Factors

Risk Factors	**Weight Values**
Occurence	0,297
Severity	0,540
Detectability	0,163
CR=0,01	

In the second step, decision matrix which consist of risk factor values and weights of risk factors were formed and normalized by use of appropriate normalisation formula. The normalized decision matrix is seen (Table 5). In the third step preference function was selected and aggregated preference functions were calculated by using pairwise comparison values for each risk factor and weighting values of risk factors. Then, by use of aggregated preference functions, entering flow, leaving flow values and net outranking flow values were calculated. (Table 6) shows entering flow values, leaving flow values and net outranking flow values.

Table 5. PROMETHEE Normalized Decision Matrix

	Occurence	**Severity**	**Detectability**
Difference in Raw Material Lots (Colour Tone Problem)	0	0,50	0,333
Holes on Shoe Sole	0	1	0,666
Combustion of Raw Material	0	0	1
Make Wrong Encolouring in Finishing	1	0,166	0
Wrong Labelling	1	0,666	0,167
Weighted Values of Risk Factors	**0,297**	**0,540**	**0,163**

Table 6. Leaving Flows, Entering Flows and Outranking Flows of Each Failure Modes

Failure Modes	Leaving Flows	Entering Flows	N.Outranking Flows
Difference in Raw Materials Lots (Colour Tone Problem)	0,279	0,133	- 0,146
Holes on Shoe Sole	0,162	0,422	0,260
Combustion of Raw Material	0,464	0,150	- 0,314
Make Wrong Encolouring in Finishing	0,314	0,245	- 0,069
Wrong Labelling	0,106	0,409	0,303

Conclusion

In this study we used AHP and PROMETHEE techniques in the FMEA to overcome drawbacks of traditional RPN calculation formula. First we calculated RPN numbers of failure modes and prioritised these failure modes by RPN numbers. Second we used AHP method for prioritisation of failure modes. Third PROMETHEE method were employed in prioritisation of failure modes. For comparison, acquired results and ranking values from all these methods proposed in (Table 7)

As seen the table 7, "Holes on shoe sole" and "Wrong labelling" failure mode have same RPN values (80). Also, "Combustion of raw material" and "Make wrong encolouring in finishing" failure modes have same RPN values too. However, risk factor values of these failure modes are different, same RPN values are acquired from multiplying these factor values and this is one of the most imported drawbacks of traditional RPN formula. Because of this drawback we couldn't prioritised these failure mode by RPN. To overcome this drawback we used AHP-RPN approach in prioritisation of failure modes. With used of AHP method we prioritised of failure modes using weights of failure modes. Weighting values are determined relying on pair wise comparison of failure modes by use of AHP scale. So, acquired results from AHP-RPN method based on individual assessment of FMEA team members. However, relative importance of FMEA risk factors is not taking into consideration in not only traditional RPN formula, but also AHP-RPN method. Because of occurrence, severity and detectability factors are not equally important for many companies, we should take into consideration weights of these risk factors. For this reason, as third method PROMETHEE is employed in prioritisation of failure modes. Because, in this method weight values of risk factors take account of prioritisation. Consequently, comparing to other two methods, PROMETHEE method is more proper for prioritisation of failure mode in FMEA. Because, with use of this method, many drawbacks of traditional RPN calculating formula are eliminated.

Table 7. Final Ranking of Failure Modes by Three Methods

Failure Modes	**Traditional RPN**		**AHP-RPN**		**PROMETHEE**	
	RPN	**Rank**	**AHP RPN**	**Rank**	**N. O. Flow**	**Rank**
Difference in Raw Materials Lots (Colour Tone Problem)	42	3	3,74	4	- 0,146	4
Holes on Shoe Sole	80	1	35,6	1	0,260	2
Combustion of Raw Material	40	2	10,48	3	- 0,314	5
Make Wrong Encolouring in Finishing	40	2	2,08	5	- 0,069	3
Wrong Labelling	*80*	*1*	*12,16*	*2*	*0,303*	*1*

REFERENCES

Avikal, S., Mishra, P.K. and Jain, R. (2013), A Fuzzy AHP and Promethee Method-Based Heuristic for Disassembly Line Balancing Problems, **International Journal of Production Research**, Vol: 51

Braglia, M. (2000), MAFMA: Multi-Attribute Failure Mode Analysis, **International Journal Of Quality & Reliability Management**, Vol:17

Bruno, G., Esposito, E., Genovese, A. and Passaro, R. (2009), The Analytic Hierarcy Process in the Supplier Selection Problem, **Proceedings of 10th Annual International Symposium on Analytic Hierarchy Process**, Pittsburgh, ABD

Chang, K., H. (2009), Evaluate the Ordering os Risk for Failure Problems Using a More General RPN Methodology, **Microelectronics Reliability,** Vol: 49

Chen, K., J. and Lee, Y., C. (2007), Risk Priority Evaluated by ANP in Failure Mode and Effect Analysis, **Quality Tolls and Techniques,** Vol: 4

Chen, H., Y., Wang, C., T. and Wu, Y., C. (2011), Strategic Decisions Using the Fuzzy PROMETHEE for IS Outsourcing, **Expert Systems With Application,** Vol: 38

Chin, K., S., Wang, M., W., Poon, G., K., K. and Yang, J., B. (2009), Failure Mode and Effect Analysis by Data Envelopment Analysis. **Decision Support Systems, Vol:** 8

Hu, A., H., Hsu, C., W., Kuo T., C. and Wu, W., C. (2009), Risk Evaluation of Green Components to Hazardous Substance Using FMEA and FAHP, **Expert Systems with Applications,** Vol: 36

Kutlu, A., C. and Ekmekçioğlu, M. (2012), Fuzzy Failure Modes and Effect Analysis by Using Fuzzy TOPSIS-Based Fuzzy AHP, **Expert System with Applications,** Vol: 39

Liu H., C., Liu, L. and Mao, X., L. (2012), Risk Evaluation in Failure Mode and Effect Analysis with Extended VIKOR Method Under Fuzzy Environment. **Expert Systems with Applications,** Vol: 39

Maheswaran, K. and Loganathan, T. (2013), A Novel Approach for Prioritizaton of Failure Modes in FMEA Using MDCM, **International Journal of Engineering Research and Applications**, Vol:3

Ömürbek, N., Üstündağ, S. and Helvacıoğlu Ö., C. (2013), Kuruluş Yeri Seçiminde Analitik Hiyerarşi Süreci (AHP) Kullanımı: Isparta Bölgesi'nde Bir Uygulama,**Yönetim Bilimleri Dergisi,** Sayı: 21

Öztekin, C. (2006), **Hizmet Sektöründe Hata Türü Etkileri Analizi ve Bir Uygulama**, Unpublished Master Thesis, Marmara University Institute of Social Sciences, İstanbul

Pillay, A. and Wang, J. (2003), Modified Failure Mode and Effect Analysis Using Approximate Reasoning, **Reliability Engineering and System Safety,** Vol: 79

Saaty, T., L. (1980), **The Analytic Hierarchy Process,** McGraw-Hill, ABD

Saaty, T., L. (1987), The Analytic Hierarchy Process – What It is and How It is Used, **Mathematical Modelling, Vol:** 9

Sofyalıoğlu, Ç. (2011), Grey Evaluation Model of Process Failure Mode Effect Analysis. **Ege Akademik Bakış,** Vol: 1

Taillandier, P. and Stinckwich, S. (2011), Using the Promethee Multi Criteria Decision Making Method to Define New Exploration Strategies for Rescue Robots, **IEEE International Symposium on Safety, Security and Rescue Robotics,** 1-5 November, Kyoto, Japan

Tay M., K. and Lim C., P. (2006), Fuzzy FMEA with a Guided Rules Reduction System for Prioritization of Failures, **Internatioal Journal of Quality & Reliability Management,** Vol: 23

Vencheh, A., H., Hejazi, S. and Eslamiasab, Z. (2013), A Fuzzy Lineer Programming Model for Risk Evaluation in Failure Mode and Effect Analysis, **Neural Comput & Applic,** Vol: 22

Wang Y., M., Chin K., S., Poon, G., K., K. and Yang, J., B. (2009), Risk Evaluation in Failure Mode and Effect Analysis Using Weighted Geometric Mean, **Expert Systems with Applications,** Vol: 36

Yılmaz, B. and Dağdeviren, M. (2010), Comparative Analysis of PROMETHEE and Fuzzy PROMETHEE Methods in Equipment Selection Problem, **Gazi Üniversitesi Mühendislik ve Mimarlık Fakültesi Dergisi**, Vol:25