Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University | http://www.saujs.sakarya.edu.tr/

Title: Risk Priority With Fuzzy Logic: Application of A Textile Factory

Authors: Tülay Korkusuz Polat

Recieved: 2018-09-10 00:00:00
Revised: 2018-10-08 12:00:00
Accepted: 2018-11-06 00:00:00
Article Type: Research Article
Volume: 23
Issue: 2
Month: April
Year: 2019
Pages: 203-212

Sakarya University Journal of Science 23(2), 203-212, 2019

Risk Priority with Fuzzy Logic: Application of a Textile Factory

Tülay KORKUSUZ POLAT*

Abstract

The most important reality in the business life that has not changed in the last fifty years is perhaps the necessity for the "customer satisfaction to be sustainable." Every failure that adversely affects product quality also causes customer dissatisfaction. In this study, the Failure Mode and Effects Analysis (FMEA) was used to analyze the potential quality failures of the production system in a textile factory. By using this method, the probability, severity and detectability of quality faults (quality risks) which could lead to customer dissatisfaction were determined. In this method, the risk magnitudes are found by multiplying the probability, severity and detectability values of risks. These risks with high priority, which are also called the Risk Priority Numbers (RPN), are the risks which need to be considered as priority, and for which more resources are needed to be allocated. These three components are equally effective when determining the Risk Priority Number because of the multiplication operation. However, when ranking the risks, the role of the severity component is more important than the others. This is because a risk of low severity may rank low in the priority order even if it occurs very frequently (even if it has a high probability). Similarly, in the exact opposite condition, even if the probability is low, a risk with a high severity needs to be placed higher in the priority order, and more resources are needed to eliminate such risks. Due to this uncertain situation, prioritization has also been made by creating a rule-based fuzzy logic in MATLAB, with the assumption that it is more meaningful to use fuzzy expressions instead of definite expressions when determining the magnitudes of risks.

Key words: Failure Mode Effect Analysis, Fuzzy Logic, Risk Priority

1. INTRODUCTION

With increased customer expectations, along with increased competitors, "being able to produce quality products" has been one of the key factors to ensuring the sustainability of competitiveness. Moreover, the way to establish a sustainable relationship with customers is to meet customer needs more conveniently than the competitors. Therefore, protecting the existing quality and improving quality are some of the important requirements for companies.

In recent years, difficulties are also experienced in the textile sector, which is one of the leading sectors of our country in terms of both employment and exports, due to economic constraints as well as the fact that global competition conditions have become more difficult. It is important to increase productivity and quality in the sector in order to overcome these difficulties. As is known, "quality" necessitates that measures can be taken before problems arise. And quality analyses need to be carried out effectively in order to be able to take measures and accomplish the necessary improvements. FMEA, which is one of the quality improvement techniques, is a technique used to systematically analyze all kinds of design and/or process-based failures that

* Corresponding Author Address: Faculty of Engineering, Department of Industrial Engineering Sakarya University, 54187, Sakarya TURKEY. E-mail address: korkusuz@sakarya.edu.tr Phone: +902642955687

may develop in a product, and the risks that these failures may create. It is a technique that uses the components of the "probability of occurrence of a failure", the "effect of the failure after its occurrence" and the "detectability of the failure" when determining the magnitudes of possible failures. In the classic FMEA, the values of these three components are multiplied when determining the magnitudes of failures. However, it is not always possible to determine the exact values of these components. Thus, there is the theory of "Fuzzy Logic" developed for situations where there is no certainty. Fuzzy logic is a theory developed by Zadeh, claiming that the propositions that are absolute true and false in the classical logic are not always possible, and that there is another proposition called uncertainty.

This study was carried out in a textile factory. Continuously occurring failures in the production of the textile factory can cause great variations in product quality. Customer dissatisfaction caused by such variations caused the company to experience huge financial losses. The company was, at that time, able to identify through classical methods which known failures could cause a major problem and which could not. However, it was not able to detect any major potential failures in this way. So, it was unable to produce solutions to failures that could potentially cause major risks. The main purpose of this study was to figure out the priority risks by identifying the size of major production failures determined together with the experts in the company. To do that, first, a FMEA was carried out in a classical way. However, since it was discovered that there were some uncertainties in the determination of the values, the FMEA was applied through the fuzzy logic theory. The implementation of the fuzzy logic was carried out through MATLAB. And, risks were prioritized as fuzzy. The two methods were compared and the recommendations for improvement were discussed.

2. MATERIALS AND METHOD

FMEA a powerful analytical technique for estimating risks and preventing errors. It is based on the fact that the problem is perceived as a customer by the emergence of the fault. This method, which is used frequently in areas including advanced electronic and mechanical equipment which produces critical products in terms of safety in advanced manufacturing systems such as automotive and space. Estimation of probability, severity and detectability for all faults identified in the FMEA study.

FMEA will reduce warranty costs and other costs associated with product failures by making products more secure. FMEA will shorten product development times by identifying problems at the beginning of operations. In Carlson's (2012) study, He mentioned that FMEA was a technique that helped the firm better meet customers' demands by identifying problems before consumers notice them.

According to Liu and his friends (2018), FMEA is a method used to identify and remove all the places and areas where potential errors may arise in the design and manufacturing process of a product. And they added that FMEA is a common method of analysis for many different industries in their study.

Rodhe (2007) is listed gains of performing FMEAs as follows:

- FMEA is an integrated process to identify and prioritize risks. By setting priorities, you can spend your limited and precious resources on the most important things,
- FMEAs produce failure modes diagrams, which are enormous resources for training, troubleshooting, root cause analyses, and process improvement,
- FMEAs supply a method to credibly communicate risks throughout the organization, as well as to leadership and to regulators, which can help secure financial supporting and aid for the right projects. Using FMEA demonstrates you really do understand the risks in your organization and are interested in reducing them,
- FMEAs handle proactive requirements for process improvement and quality,
- FMEAs deal with Joint Commission and other regulatory requirements.

FMEA is one of the risk assessment techniques. Liu and his friends (2013) adverted that in the classic FMEA technique, RPN is used to calculate the risks of error types in the system. And they added in their studies that RPN is obtained by multiplying three risk components - Severity (S), Occurrence (O) and Detectability (D). According to Rezaee and his friends (2018), the aim of the calculation of RPN, identify high-level mistakes and thus ensure that resolutions with high RPN score resolve more preferentially. But in the Rezaee and his friends' study (2018), they mentioned that RPN has some weak points. In the classic RPN calculation, the weights of severity, occurrence and detectability components are assumed to be the same and relative importance is not included in this calculation.

FMEA consists of nine basic steps (Yücel, 2007):

1. FMEA planning to determine the objectives and levels of FMEA,
2. Defining specific procedures, main principles and criteria for the implementation of FMEA,
3. Analyzing the system according to functions, interaction areas, activity stages, activity types and environment,
4. Creating and analyzing fault tree diagrams, and task and reliability diagrams to show processes, mutual connections and dependencies,
5. Identifying potential failure types,
6. Assessing and classifying failure types and their effects,
7. Defining measures to prevent and control failures,
8. Assessing the effects of the proposed measures,
9. Documenting results.

Figure 1 shows the functioning of FMEA (Özkılıç, 2005).

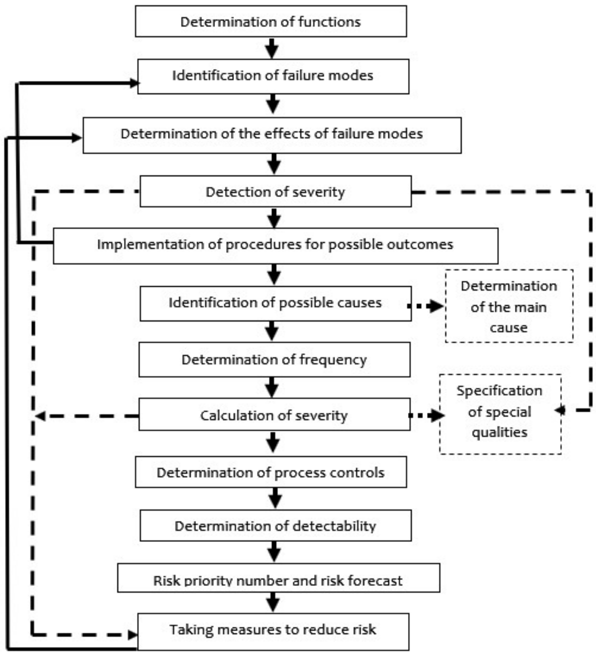


Figure 1: Process of FMEA

A relative ranking can be made within the scope of the specific FMEA. For example, the values of the risk components used in the FMEA are shown in table 1 (Sofyalıoğlu, 2011):

Table 1: Scales used in FMEA technique

(1) OCCURENCE		
Criteria	**Score**	**The likelihood of possible errors**
The chances of failure are remote	1	0
	2	1/20000
Low error rate	3	1/10000
	4	1/2000
Medium error rate	5	1/1000
	6	1/200
High error rate	7	1/100
	8	1/20
Very high error rate	9	1/10
	10	1/2
(2) SEVERITY		
Impact of the mistake on the customer		**Score**
The customer probably does not matter		1
Slight discomfort		2, 3
Customer dissatisfaction		4, 5, 6
High level of dissatisfaction		7, 8
Safety / legislation results		9, 10
(3) DETECTABILITY		
Likelihood of error being recognized	**Score**	**Probability of error reaching the customer**
Far	1	0-5
	2	6-15
Low	3	16-25
	4	26-35
Medium level	5	36-45
	6	46-55
High	7	56-65
	8	66-75
Very high	9	76-85
	10	86-100

Wang and colleagues (2009) say the FMEA focuses on preventing the creation of faults and enhancing safety and customer satisfaction. Because FMEA is a useful technique for designers and is widely used in a wide range of industries (Chang and Cheng (2011); Tooranloo and Ayatollah (2016); Rezaee et al. (2018); Wang et al. (2009)).

McAndrew and Vishnevskaya (2018) explained the general concepts are taught to enable anyone to undertake a review to improve quality. Whether technical, practical or committed to quality their book covers all the ways to be proactive in planning a Failure Mode Effects Analysis.

Fuzzy logic is a useful technique for defining and resolving uncertainties and indefinite real problems. Fuzzy logic is a multivariate theory that uses average values such as “middle”, “high”, and “low” instead of classical variables such as “yes” or “no”, or “true” or “false” (Aydın and Eren, 2018).

Zadeh’s concept of “fuzzy set” has emerged from the fact that mathematical methods of the classical system theory are insufficient in many systems in the real world, especially in complex systems that involve people. Zadeh has proposed that attributions like “long, red, and static” should be defined as fuzzy sets expressed by a graded membership function instead of classical clusters expressed by a binary membership function (Kıyak ve Kahvecioğlu, 2003).

Tanaka (1997) identified that Fuzzy logic is a broad theory including fuzzy set theory, fuzzy logic, fuzzy measure and others. Fuzzy set theory is an increase of conventional set theory. Fuzzy logic is an increase of conventional (binary) logic. Fuzzy measure is an increase of probability measure. Fuzziness, as handled in fuzzy logic, can apply to diverse types of vagueness and uncertainty but particularly to the vagueness related to human linguistics and thinking, and it is different from the uncertainty handled by probability theory. Probabilistic uncertainty is, for instance, the chance of getting three by throwing a die. Probabilistic uncertainty can be evaluated objectively by repeated trials.

There are uncertainties at the root of many problems in the industry and many techniques have been developed to model them. Nguyen and Walker (2005) describe that fuzzy sets deal with the type of uncertainty that arise when the boundaries of a class of objects aren't sharply defined. Regarding this, we can see different examples like "young", "heat", "high income". Membership in such classes is an issue of degree rather than certainty one way or another, and it is specified mathematically by fuzzy sets.

Mathematical Fuzzy Logic (a philosophical and computational approach to the problems of uncertainty and precision, which has emerged to provide robust logical bases for fuzzy set theory) has begun to be an important subdivision of mathematical logic. Handbook of Mathematical Fuzzy Logic (2011) focuses on many-valued logics with linearly ordered truth values and has yielded elegant and deep mathematical theories and challenging problems, thus continuing to attract an ever increasing number of researchers.

There are many sources in-depth explaining fuzzy logic with examples (Ross (2017), Belohlavek et al. (2017), Klir and Yuan (1995), Bhargava (2013)).

3. RESULTS

Continuously occurring failures in the production of the textile factory could cause great variations in product quality. Customer dissatisfaction caused by such variations caused the company to experience huge financial losses. The company was able to identify through classical methods which of the existing failures were important and which were not. However, it could not detect any major potential failures in this way. So, it was unable to produce solutions to failures that could potentially be risky. The most problematic 13 risks of production causing customer dissatisfaction in the textile factory where the study was carried out were identified together with the company authorities. We can list these risks as follows:

1. Shrinkage of size caused by workers,
2. Failure occurring in patterns caused by step inconsistencies,
3. Deformation caused by a deviation from the direction of stitching,
4. Quality caused by loose stitching,
5. Accumulation of stitches in the fabric during sewing,
6. The sewing machine's skipping stitches during sewing,
7. The machine's dislocating stitches while creating a pattern,
8. Ripping caused by lack of attention,
9. Stitch puckering caused by the pulling of thread,
10. Sewing spangles of a pattern in the wrong spot,
11. The risk for workers to create button-holes in the wrong spot,
12. Needle breakage during sewing,
13. Symmetry failure caused by parts' being confused with other products.

The identified risks were analyzed using the FMEA technique in order to determine their magnitudes. And, the probabilities of occurrence, severity and detectability of the risks were assessed on a scale of ten. Table 2 shows the results of the FMEA of the risks.

Table 2: Assessing risks with FMEA

RISKS	O	S	D	RPN
Shrinkage of size caused by workers	6	6	9	324
Failure occurring in patterns caused by step inconsistencies	3	8	4	96
Deformation caused by a deviation from the direction of stitching	5	6	4	120

Quality caused by loose stitching	4	7	4	112
Accumulation of stitches in the fabric during sewing	7	4	4	112
The sewing machine's skipping stitches during sewing	2	3	8	48
The machine's dislocating stitches while creating a pattern	6	6	7	252
Ripping caused by lack of attention	5	3	2	30
Stitch puckering caused by the pulling of thread	8	2	4	64
Sewing spangles of a pattern in the wrong spot	4	5	5	100
The risk for workers to create button-holes in the wrong spot	3	7	3	63
Needle breakage during sewing	9	1	1	9
Symmetry failure caused by parts' being confused with other products	2	10	3	60

The probability, severity and detectability levels of the risks presented in Table 2 were determined together with the experts working in the company. For example, the likelihood of the risk of "shrinkage of size due to workers" was determined to be 6, the effect after its occurrence was determined to be 6, and its detectability was determined to be 9. The value of the RPN is found by multiplying the probability, severity and detectability. Risks with high RPN values are the first priority according to the multiplication results. In other words, although these three factors seem to have an equal power in the determination of the result, the risks rather have a stronger role to play in the priority order. Therefore, it is necessary to assess each risk separately.

With the assumption that the role of each of the three risk components would not be the same and may change based on the condition of the risk in question, the risks that were identified in this study were assessed by creating a rule-based fuzzy logic in MATLAB — a software development tool designed for the solution and analysis of technical calculations and mathematical problems.

A fuzzy controller structure was set up to determine which of the production risks in the company was more important and to rank the risks according to their priorities. Since there are three components (probability of occurrence, subsequent effect (or severity) and detectability values) determining the priority of risks in the FMEA risk assessment technique, a fuzzy logic controller with 3 inputs and 1 output was designed.

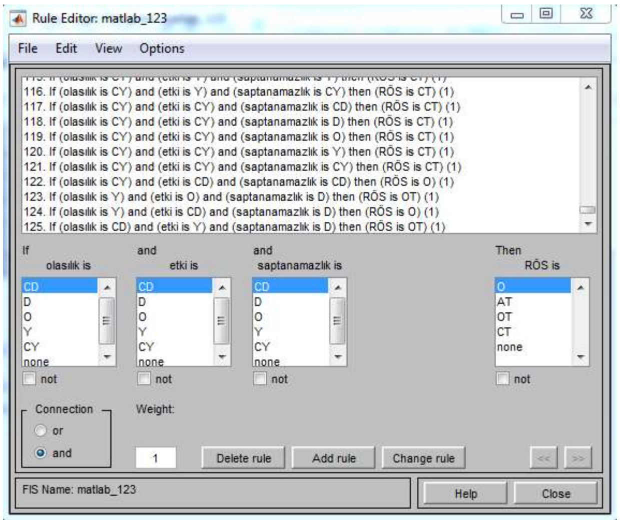
- The first input was the probability. The probability was divided into five levels. These were Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH).
- The second input was the effect. This risk component was also divided into five levels. These were Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH).
- The third input was the detectability. This risk component was also divided into five levels. These were Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH).
- The output was the Risk Priority Number. This was divided into four levels. These were Insignificant (I), Slightly Dangerous (SD), Moderately Dangerous (MD) and Very Dangerous (VD).

During the creation of membership functions of the inputs and outputs:

- Three inputs and one output were added to the fuzzy logic designer window,
- The levels created in the fuzzy set were inserted in the membership function editor, by adding a triangular membership function for each input and the output. The slope of the membership function of the inputs and the output was made triangular. This step was repeated for each input and the output.
- In the rules editor, the output was set by processing the probability input, effect input and detectability input of the

membership functions through the "and" function. A total of 5×5×5 = 125 rules were written sincere there were 5 levels for each input. Table 3 shows the rules.

Table 3: Matlab Rule Editor



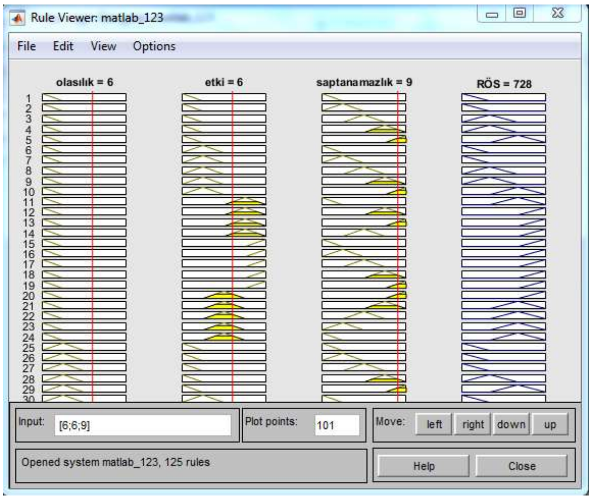
As seen in Table 3 (rule 123), the Risk Priority Number is "moderately dangerous (MD)", if the probability is high (H), the effect is medium (M) and the detectability is low (D). These rules were, again, prepared together with the production specialists who worked in the company.

Results: The values of the output were observed according to the inputs, and the results were calculated using the MATLAB center of gravity method.

Assessment of Risk Priorities

The rule-based fuzzy logic was used to determine risk priorities for the 13 risks identified in the company. Table 4 shows the assessment carried out for the risk of "shrinkage of size caused by workers."

Table 4: "The risk of shrinkage of size caused by workers" risk assessment



If the probability value, effect value, and detectability value of the risk of "shrinkage of size caused by workers" — for which the fuzzy logic assessment is shown in Table 4 — are 6, 6, and 9, respectively, the fuzzy risk priority number will be 728. This value would normally be 324, if it were found by calculating the risk priority number (by probability × severity × detectability).

Similarly, fuzzy logic assessments were carried out for the other 12 risks. Based on this assessment, Table 5 shows the fuzzy risk priority numbers of all risks.

Table 5: Fuzzy risk priority numbers of all risks

RISKS	O	S	D	FRPN
Shrinkage of size caused by workers	6	6	9	728
Failure occurring in patterns caused by step inconsistencies	3	8	4	879
Deformation caused by a deviation from the direction of stitching	5	6	4	555
Quality caused by loose stitching	4	7	4	632
Accumulation of stitches in the fabric during sewing	7	4	4	527
The sewing machine's skipping stitches during sewing	2	3	8	594

The machine's dislocating stitches while creating a pattern	6	6	7	694
Ripping caused by lack of attention	5	3	2	333
Stitch puckering caused by the pulling of thread	8	2	4	518
Sewing spangles of a pattern in the wrong spot	4	5	5	667
The risk for workers to create button-holes in the wrong spot	3	7	3	654
Needle breakage during sewing	9	1	1	272
Symmetry failure caused by parts' being confused with other products	2	10	3	888

According to these results, Table 6 shows how the risks rank according to the "fuzzy risk priority numbers (FRPNs)."

Table 6: Ranking of the production risks according to the "Fuzzy Risk Priority Numbers" (significant less important ranking)

RISKS	Results
Symmetry failure caused by parts' being confused with other products	888
Failure occurring in patterns caused by step inconsistencies	879
Shrinkage of size caused by workers	728
The machine's dislocating stitches while creating a pattern	694
Sewing spangles of a pattern in the wrong spot	667
The risk for workers to create button-holes in the wrong spot	654
Quality caused by loose stitching	632
The sewing machine's skipping stitches during sewing	594
Deformation caused by a deviation from the direction of stitching	555
Accumulation of stitches in the fabric during sewing	527
Stitch puckering caused by the pulling of thread	518
Ripping caused by lack of attention	333
Needle breakage during sewing	272

According to the ranking given in Table 6, the risk of "symmetry failure caused by parts' being confused with other products" and the risk of "failure occurring in patterns caused by step inconsistencies" are highly dangerous.

4. DISCUSSION

According to the ranking given in Table 6, there are two risks that we can consider to be in the high-danger level. These are the risk of "symmetry failure caused by parts' being confused with other products" and the risk of "failure occurring in patterns caused by step inconsistencies."

These results were shared with the company, and the measures to be taken for the risks that were in the high-danger level were determined. For example, for the risk of "symmetry failure caused by parts' being confused with other products," every part was placed on the counter of the product that it belonged to. In other words, it was no longer necessary to go to the warehouse to get parts every time. This way, pieces were also prevented from being sewn on the wrong product due to the lack of attention of workers. Likewise, the periodic maintenance frequency of the counter was increased for the risk of "failure occurring in patterns caused by step inconsistencies."

Before this study, the company thought that its greatest risk was the risk of "needle breakage during sewing." This is because this risk was more likely to take place than the other risks. However, the possibility of occurrence is not sufficient to prioritize risks alone. Effect and detectability are also important components for prioritizing risks. Especially the effect, that is, the severity of failure, is a more significant component for customer satisfaction compared to the other components.

Table 7 shows that although the risks have the same probability, severity and detectability values, different results are obtained when classical and fuzzy calculations are carried out in the determination of the risk magnitudes (FRPN: Fuzzy Risk Priority Number).

Table 7: Classic and fuzzy calculation results

	O	S	D	RPN	FRPN
Shrinkage of size caused by workers	6	6	9	324	728
Failure occurring in patterns caused by step inconsistencies	3	8	4	96	879
Deformation caused by a deviation from the direction of stitching	5	6	4	120	555
Quality caused by loose stitching	4	7	4	112	632
Accumulation of stitches in the fabric during sewing	7	4	4	112	527
The sewing machine's skipping stitches during sewing	2	3	8	48	594
The machine's dislocating stitches while creating a pattern	6	6	7	252	694
Ripping caused by lack of attention	5	3	2	30	333
Stitch puckering caused by the pulling of thread	8	2	4	64	518
Sewing spangles of a pattern in the wrong spot	4	5	5	100	667
The risk for workers to create button-holes in the wrong spot	3	7	3	63	654
Needle breakage during sewing	9	1	1	9	272
Symmetry failure caused by parts' being confused with other products	2	10	3	60	888

Table 7 shows the risk magnitudes according to classical and fuzzy calculations. For example, the risk of "needle breakage during sewing" was the most dangerous risk in the assessment carried out only by considering the probability, whereas it can be considered the least important risk based on the calculation made in this study.

CONCLUSIONS

In this study, a FMEA — a technique involving the identification of the risks of known or potential failures, prioritization of the risks, and the planning of the necessary improvements to avoid these failures — was carried out by focusing on production failures in a textile factory. The technique was implemented both by using the classical method and — with the assumption that the values of the risk components are not always definite — by using the fuzzy method.

Fuzzy implications were made using rules when prioritizing the risks. The resulting output sets were identified, which were determined by each rule and were matching the inputs to the output at that time. The resulting fuzzy set was passed without clarification, and the sharp output value was found for the inputs in that range. Thus, more effective results were obtained.

Based on the fuzzy risk prioritization, the prioritization conditions of the risks of quality in the production line were identified more realistically. Improvement plans were made to get rid of the adversities that may be caused by the priority risks and to enhance the quality and reliability of the products. Thus, customer satisfaction was improved, and it was ensured that potential product failure were identified and avoided before the product was bought by the customer. At the same time, the cost of defective production was reduced.

REFERENCES

[1] C.S. Carlson "Effective FMEAs: Achieving Safe, Reliable, and Economical Products and Processes using Failure Mode and Effects Analysis", Wiley, New Jersey, 1st Edition, 2012, ISBN-10: 1118007433 ISBN-13: 978-1118007433

[2] Y. Liu, Z. Kong, Q. Zhang "Failure modes and effects analysis (FMEA) for the security of the supply chain system of the gas station in China", *Ecotoxicology and Environmental Safety*, 164, pp. 325-330, 2018

[3] K. R. Rodhe “Failure Modes and Effect Analysis: Templates and Tools to Improve Patient Safety”, HCPro Inc., 1st Edition, USA, 2007, ISBN-10: 1601460295 ISBN-13: 978-1601460295

[4] H-C. Liu, L. Liu, N. Liu “Risk evaluation approach in failure mode and effects analysis: A literature review”, *Expert Systems with Applications* 40, pp. 828-838, 2013

[5] M.J. Rezaee, S. Yousefi, M. Valipour, M.M. Dehdar “Risk analysis of sequential processes in food industry integrating multi-stage fuzzy cognitive map and process failure mode and effects analysis”, *Computers&Industrial Engineering* 123 pp. 325-337, 2018

[6] Ö. Yücel “Konfeksiyon üretiminde hata türü ve etkileri analizi”, *Tekstil ve Konfeksiyon* 2, sayfa 126-131, 2007

[7] Ö. Özkılıç “İş Sağlığı ve Güvenliği Yönetim Sistemleri ve Risk Değerlendirme Metodolojileri”, TİSK Yayınları, Ankara, 2005

[8] Ç. Sofyalıoğlu “Süreç Hata Modu Etki Analizini Gri Değerlendirme Modeli”, *Ege Akademik Bakış/Ege Academic Review*, Cilt 11, Sayı 1, sayfa 155-164, 2011

[9] Y-M. Wang, K-S. Chin, G.K.K. Poon, J.B. Yang “Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean”, *Expert Systems with Applications* 36, pp. 1195-1207, 2009

[10] K-H. Chang, C-H. Cheng “Evaluating the risk of failure using the fuzzy OWA and DEMATEL method”, *Journal of Intelligent Manufacturing* 22, pp. 113-129, 2011

[11] H.S. Tooranloo, A.S. Ayatollah “A model for failure mode and effects analysis based on intuitionistic fuzzy approach”, *Applied Soft Computing* 49, pp. 238-247, 2016

[12] I. McAndrew, E. Vishnevskaya “Failure Mode Effects Analysis: A Practical Approach”, AP Lambert Academic Publishing, 2018, ISBN-10: 6134973122 ISBN-13: 978-6134973120

[13] Y. Aydın, T. Eren “Hava savunma sanayii alt yüklenici seçiminde bulanık mantık altında çok kriterli karar verme ve hedef programlama yöntemlerinin kullanılması”, *Journal of Aviation* 2, sayfa: 10-30, 2018

[14] E. Kıyak, A. Kahvecioğlu “Bulanık mantık ve uçuş kontrol problemine uygulanması”, *Havacılık ve Uzay Teknolojileri Dergisi* Cilt 1, Sayı 2, sayfa 63-72, 2003

[15] K. Tanaka “An Introduction to Fuzzy Logic for Practical Applications”, Springer, 1996th Edition, ISBN-13: 978-0387948072 ISBN-10: 0387948074

[16] H.T. Nguyen, E.A. Walker “A First Course in Fuzzy Logic”, Chapman and Hall/CRC Press Taylor&Francis Group, Third Edition, Boca Raton, 2005

[17] Handbook of Mathematical Fuzzy Logic – Volume 1, P. Cintule, P. Hajek, C. Noguere (Editors), College Publications, 2011, ISBN-10: 1848900392 ISBN-13: 978-1848900394

[18] T.J. Ross “Fuzzy Logic with Engineering Applications”, Wiley, 4th Edition, UK, 2017, ISBN-13: 978-1119235866 ISBN-10: 1119235863

[19] R. Belohlavek, J.W. Dauben, G.J. Klir “Fuzzy Logic and Matmematics: A Historical Perspective”, Oxford University Press, UK, 2017, ISBN-13: 978-0190200015 ISBN-10: 0190200014

[20] G.J. Klir, B. Yuan “Fuzzy Sets and Fuzzy Logic: Theory and Applications”, Prentice Hall, 1st edition, 1995, ISBN-13: 978-0131011717 ISBN-10: 0131011715

[21] A.K. Bhargava “Fuzzy Set Theory, Fuzzy Logic and Their Applications”, S. Chand & Company Pvt. Ltd., First Edition, New Delhi, 2013, ISBN-13: 978-8121941945 ISBN-10: 8121941946