(REFEREED RESEARCH)

FAILURE MODES AND EFFECTS ANALYSIS USING FUZZY TOPSIS IN KNITTING PROCESS

ÖRME SÜRECİNDE BULANIK TOPSIS KULLANARAK HATA TÜRÜ VE ETKİLERİ ANALİZİ

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ABSTRACT

It is significant to identify and eliminate or minimize faults in order to provide customer satisfaction. Failure Mode and Effects Analysis (FMEA) is recognized as an operative tool for the quality improvement. This study carried out FMEA in knitting process using fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The fuzzy approach was integrated into the TOPSIS because of its ability to deal with the imprecision and vagueness in real world problems. In this manner, classifying failures into priority classes by experts using linguistic variables allows managers to be focused on the most critical ones with more robust priority ranking. According to the obtained results in this study, it was determined roller shooting mistake, oil stain, measurement inequality, touching error, number of hole, pattern error and yarn breakage are the most critical faults. These failure modes are usually caused by the fact that the adjustments of the knitting machine are not set properly. In order to troubleshoot these errors; it is significant to increase the number and quality of trainings in the factory, ensure their continuity and carry out regular machine maintenance.

Keywords: FMEA, failure, fuzzy, TOPSIS, fuzzy TOPSIS, knitting

ÖZET

Müşteri memnuniyetini sağlamak için hataları tespit etmek, ortadan kaldırmak veya en aza indirmek önemlidir. Hata türü ve etkileri analizi (HTEA), kalite iyileştirme için etkin bir araç olarak kabul edilmektedir. Bu çalışmada; FMEA, örme sürecinde bulanık TOPSIS kullanılarak gerçekleştirilmiştir. Bulanık mantığın gerçek dünya problemlerindeki kesin olmayan enformasyonla ve belirsizlikle başa çıkma becerisi nedeniyle, bulanık yaklaşımı TOPSIS tekniğine entegre edilerek kullanılmıştır. Bu şekilde, hataların uzmanlar tarafından dilsel değişkenler kullanılarak önceliklendirilmesi, yöneticilerin daha güçlü öncelik sıralamasına sahip en kritik olanlara odaklanmalarına olanak tanır. Bu çalışmada elde edilen sonuçlara göre, merdane çekim hatası, yağ lekesi, ölçü eşitsizliği, tuşe hatası, kaçık patlak, desen hatası ve iplik kopması kritik hatalar olarak belirlenmiştir. Bu hata türleri genellikle örgü makinesinin ayarlarının doğru yapılmamasından kaynaklanmaktadır. Bu hataları gidermek için; fabrikadaki eğitimlerin sayısının ve kalitesinin arttırılması, sürekliliğinin sağlanması ve düzenli makine bakımlarının yapılması önemlidir

Anahtar Kelimeler: FMEA, hata, bulanık, TOPSIS, bulanık TOPSIS, örme

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1. INTRODUCTION

Failure mode and effects analysis (FMEA) is a powerful method for reliability analysis used throughout many sectors of industry. FMEA provides to learn the potential malfunctions and their effects, and evaluate future risks, and conduct preventive measures in order to fulfill customer requirement for quality and reliability (1). In order to describe each failure mode three parameters namely severity, occurrence, and detection are utilized. Severity (S) refers to the seriousness of the effect of a failure to the customers. Occurrence (O) refers to the likelihood of the failure occurring. Detection (D) refers to probability of being undetected. By the multiplication of the three risk factors, the value of risk priority number (RPN) is obtained. The purpose of RPN is to prioritize the failure modes. Having higher the value of the RPN is assumed to be more risky failure modes will be tackled with more resources.

The FMEA being tackled by multiple decision-makers leads to a more trustworthy assessment. Unfortunately, the literature lacks group decision support systems for sorting failures in the field of the FMEA (2). Moreover, traditional FMEA suffers from several weaknesses (3, 4, 5, and 6): The evaluations of the failure modes usually include in imprecise and subjective information and it is very difficult for the experts to give crisp values. Secondly, the ratings of evaluation factors (S, O, and D) are assumed to have the same importance. But for the same risk factors, experts may provide different assessment information based on their expertise opinions. Lastly, the same value of RPN may be generated for two different failure modes having various values of their risk factors called S, O, D, and hence the same priority. However, the purpose of the FMEA is to assign the limited resources to high-risk items. To overcome these shortcomings, the fuzzy approach is more suitable for FMEA allowing vague and qualitative information in natural language of expert judgments. Both the risk factors' importance and the failure modes can be evaluated with linguistic variables which is the vagueness of human feeling. Therefore, this paper presents FMEA based on fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). By examining literature, it is seen that there is a limited number of studies on this subject. For example, Braglia, Frosolini, and Montanari (2003) presented a multi-attribute decision-making approach called fuzzy TOPSIS approach, which considers the failure causes as the alternatives to be ranked, the risk factors O, S and D related to a failure mode as criteria. They conducted the case study in refrigerator production line, the three risk factors and their corresponding weights of importance were allowed to be assessed using triangular fuzzy numbers (7). Similarly, Song et al. (2013) proposed FMEA analysis using integrated weight-based fuzzy TOPSIS for nuclear reheat valve system and they ranked all failure modes (8). Ekmekçioğlu and Kutlu (2012) presented fuzzy AHP and fuzzy TOPSIS methodologies for FMEA analysis and they applied to a spindle manufacturing process in a firm producing aluminum parts and dies (9). However, there is still need to do research on the fuzzy approach of the techniques of multi-criteria making decision for FMEA analysis.

With regard to textile sectors, Özyazgan and Engin (2013) applied process FMEA analysis in knitting industry (10). Similarly, Özyazgan (2014) presented FMEA analysis in order to avoid failures by estimating risks determining critical failures in company producing woven fabric (11). Kaewsom and Rojanarowan (2014) made a study of spinning machines to find out the reasons of fiber breaks (12). Küçük et al. (2016) examined all the activities during spreading and cutting processes and the source of the faults have been identified and classified with the method of FMEA (13). The significant shortage in these aforementioned papers in the literature is faced to crisp RPN computation. It is difficult for experts to assess the risk factors' importance with exact numerical values and make precise evaluations of failure modes. Differently from previous applications in the textile sector, this study contributes to the literature presenting FMEA based on fuzzy TOPSIS using imprecise data in the form of fuzzy numbers in the knitting proses.

This paper continues with the description of material and methodology. Next, the third section proposes the application in knitting process and finally the last section covers the discussion and conclusions.

2. MATERIAL AND METHOD

The factory in which this study was carried out has three shifts, 450 employees and 184 knitting machines in different types.

2.1. Material

The production process of a pullover model, which was produced in the knitting department, was selected for this study because of widely production in this factory. This model is produced in four parts as front, back, arm and collar and 0.15 kg yarn is used for the production of one. In this study, 13 types of faults have been detected for this model.

2.2. Fuzzy TOPSIS Methodology

It is a systematic approach to extend the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) to the fuzzy environment. The use of precise values in the rating of alternatives may have limitations to deal with uncertainties. Hence, it is suitable to benefit from fuzzy TOPSIS using fuzzy numbers instead of precise values in fuzzy environment. This study uses Chen's fuzzy TOPSIS method (14) for solving the multi-criteria decision making problem. The algorithms of this method are described as follows.

- The importance weights of various criteria and the ratings of qualitative criteria are considered as linguistic variables. As seen Table 1, linguistic preferences can be converted into triangular fuzzy numbers which can be used in calculations.

Table 1. Linguistic variables for importance weight of each criterion and the rating of each alternatives

Linguistic variables			
for importance weight of each criterion		for the rating of each alternatives	
Very low (VL)	(0,0,0.1)	Very poor (VP)	(0,0,1)
Low (L)	(0,0.1,0.3)	Poor (P)	(0,1,3)
Medium low (ML)	(0.1,0.3,0.5)	Medium poor (MP)	(1,3,5)
Medium (M)	(0.3,0.5,0.7)	Fair (F)	(3,5,7)
Medium high (MH)	(0.5,0.7,0.9)	Medium good (MG)	(5,7,9)
High (H)	(0.7,0.9,1)	Good (G)	(7,9,10)
Very high (VH)	(0.9,1,1)	Very good (VG)	(9,10,10)

- The evaluators give judgment values with the linguistic statements for the alternatives with respect to criteria. When k is the decision-makers, the importance of the criteria and the rating of alternatives with respect to each criterion can be calculated as

$$\tilde{w}_{ij} = \frac{1}{K}[\tilde{w}_j^1 \; (+) \; \tilde{w}_j^2 (+) \ldots (+) \; \tilde{w}_j^K], \quad (1)$$

$$\tilde{X}_{ij} = \frac{1}{K}[x_j^1 \; (+) \; \tilde{x}_j^2 (+) \ldots (+) \; \tilde{x}_j^K], \quad (2)$$

where $\tilde{w}_j^K$ and $\tilde{x}_j^K$ are the importance weight and the rating of the K th decision maker.

- Obtaining weights of the criteria ($\tilde{W}$) and the ratings of alternatives with respect to each criterion, a fuzzy decision matrix ($\tilde{D}$) can be expressed in matrix format for m alternatives and n criteria as following.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \quad \tilde{W} = [\tilde{w}_1 \quad \tilde{w}_2 \ldots \tilde{w}_3] \quad (3)$$

These linguistic variables can be described by triangular fuzzy numbers,

$\tilde{x}_{ij} = (\tilde{a}_{ij}, \tilde{b}_{ij}, \tilde{c}_{ij})$ and $\tilde{w}_{ij} = (\tilde{w}_{j1}, \tilde{w}_{j2}, \tilde{w}_{j3})$

- The normalized fuzzy decision matrix denoted by $\tilde{R}$ is shown as following formula:

$\tilde{R} = [\tilde{r}_{ij}]_{mxn}$ i=1,2,…,m j=1,2,…n

$$\tilde{r}_{ij} = \left(\frac{lij}{ujmax}, \frac{mij}{ujmax}, \frac{uij}{ujmax}\right) \text{ for the benefit criteria} \quad (4)$$

- The elements of the weighted fuzzy normalized decision matrix ($\tilde{v}_{ij}$) are calculated as

$$\tilde{v}_{ij} = \tilde{r}_{ij}\,\tilde{w}_j, \quad i = 1, \ldots, m; \quad j = 1, \ldots, n \quad (5)$$

- The fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) are defined according to the weighted normalized fuzzy decision matrix. It is known that triangular fuzzy numbers belong to the closed interval [0,1]. FPIS donated as $A^*$and FNIS donated as A^- are defined as $A^* = \{v_1^*, \ldots, v_j^*, \ldots, v_n^*\}$, $A^- = \{v_1^-, \ldots, v_j^-, \ldots, v_n^-\}$ where $\tilde{v}_j^*$= (1,1,1) and $\tilde{v}_j^-$ = (0,0,0), j=1,2,…,n (6)

- The distances (d_i^* and d_i^-) of each alternative A^* and A^- can be calculated by the vertex method which is defined to calculate the distance between two triangular fuzzy numbers. Let $\tilde{a}$ = (a_1, a_2, a_3) and $\tilde{b}$ = (b_1, b_2, b_3) be two triangular fuzzy numbers, then the vertex method is defined to calculate the distance between them. The main formula is given below:

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \quad (7)$$

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), \; i = 1, 2, \ldots, m \quad (8)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), \; i = 1, 2, \ldots, m \quad (9)$$

- A closeness coefficient (CC_i) is defined to determine the ranking the order of alternatives once the d_i^* and d_i^- of each alternative have been calculated.

$$\tilde{CC}_i = \frac{d_i^-}{d_i^* + d_i^-} \quad i = 1,2,\ldots,m \quad (10)$$

3. APPLICATION of FMEA USING FUZZY TOPSIS IN KNITTING PROCESS

The types of failure encountered during the production of the pullover model in this case are determined and these are as follows.

FM1- Touching error: Touching error is to loose or tight of knitting. This error may be occurred due to the difference in the knitting cycle settings of the machine, the instability of the shuttle and the yarn feeding system not working properly.

FM2- Measurement Inequality: It is due to not conform to the front, back, arm measurements determined by the design department in the head office

FM3 - Roller shooting mistake: It is a machine tool that helps pull the knitted piece down from the knitting area. Shooting mistakes bring a transverse line or a lumping on the texture. More often than not, these errors are due to the unsteadiness of the machine. For example, due to the pressure on both sides of the drawing rollers is different; it is observed that the elasticity of the texture and the states of the loops are changing.

FM4 – Pattern Error: It is that the patterns on the product model are not track a symmetrical state trace.

FM5 – Oil stain: It is stain of oil of needles used in machine. It can be seen as drip-shaped or vertical line in fabric. It is not possible to detect it during machine operation. The quality is checked and counted by the staff in control.

FM6 – Fly mix: The fly is the fiber clusters that accumulate in the knitting machine and mix to the fabric. Often, the fiber fragments that accumulate in the holes of the yarn guides multiply over time, knit together with the yarn, and cause unwanted unevenness in the fabric. The accumulation of fiber pellets can be avoided by simple ventilation devices or by the air conditioner in the company. In new knitting machines, yarn transfers are made through pipes in combination with absorbent air spaces. In this way the amount of fiber fly is minimized.

FM7 – Number of hole: It is the large mesh space with a diameter of 10 cm.

FM8 – Nep: It is an error or irregularity in knitted fabrics. Here, when the needle takes the new thread, it does not drop the old thread down the hill and becomes a second rope in the hook. This is seen when the needle lance is out of order or when the machine settings are tight. Also, this may be caused by the non-uniformity of the brush. The needle can make this movement several times over. This fault is also referred to as duplication (overlapping) fault, overlay or nep.

FM9 – Knitting rotation: This error, which occurs in some unbalanced knitting structures, occurs when the stitch rows and bars are not perpendicular to each other. It is a type of error that arises from the fact that the loops do not appear regularly from lack of adjustment in the machine.

FM10 – Broken needle: The needle might break because of reasons such as compulsions in the hook and tongue part of the needle of circular knitting machines, and foreign materials etc. This situation might lead to the needle causing errors in the form of lines on the fabric because of losing the capability of forming loops of the needle.

FM11 – Yarn breakage: It is caused by the breaking of a thread in a knitting machine after being fed to the needle and during the loop forming movement. It brings a little hole in the fabric. It is necessary to use quality yarn to prevent this.

FM12 – Unevenness in yarn: It is one of the most important factors affecting yarn quality in production. Because the irregularities in the yarn cause the yarn strength to decrease, the formation of thick, thick spots, and additionally the abrasion mistakes during the dyeing of the fabrics.

FM13 - Yarn delivery: It is arised from the impairment of the needle during the transfer of the knitting machine back and forth.

Figure 1 illustrates the hierarchical structure for ranking modes in this case study. Three parameters of the FMEA analysis which are severity, occurrence and detection were determined as evaluating criteria.

The decision makers composed of the three experts determined as a process manager and quality inspectors evaluate the importance weights of criteria using linguistic scale given in Table 1. The linguistic expressions can be transferred to the corresponding fuzzy numbers as seen Table 2. For example, while first decision maker expresses his insight as high, the others states which of very high for first criteria. Then, their preferences are converted to (0.7, 0.9, 1) the triangular fuzzy numbers. After transformation, the decision makers' evaluations are aggregated for determining the criteria weights using formula (1). For example, the weights of severity criteria calculated as

Similarly, the failure modes in knitting are evaluated in terms of each criterion by decision makers using linguistic variables and then these evaluations are converted to fuzzy triangular numbers using linguistic scale given Table 1. Subsequently, the fuzzy aggregated weights are calculated using Eq. (2) to construct the fuzzy failure modes evaluation matrix. Table 3 displays aggregated fuzzy decision matrix together with the normalized form. Depending on the benefit criteria, the obtained fuzzy decision matrix is normalized by Eq. (4).

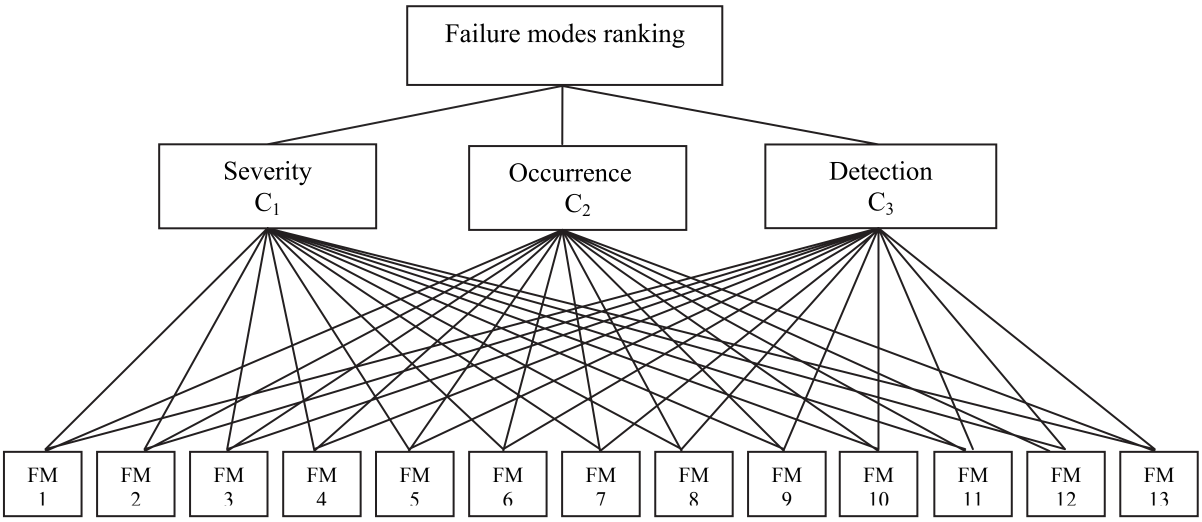

Figure 1. The hierarchical structure for the ranking of failure modes

$$\tilde{W}_1 = \frac{1}{3}[\,(0.7,0.9,1) + (0.9,1,1) + (0.9,1,1)] = (0.8333,\ 0.9667,\ 1).$$

Tablo 2. Evaluation of criteria with linguistic variables by decision makers and obtained weights

Criteria	DM1	DM2	DM3	DM1	DM2	DM3	WEIGHTS
C_1	H	VH	VH	(0.7,0.9,1)	(0.9,1,1)	(0.9,1,1)	(0.8333,0.9667,1)
C_2	MH	M	M	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3667, 0.5667, 0.7667)
C_3	H	H	MG	(0.7,0.9,1)	(0.7,0.9,1)	(0.5,0.7,0.9)	(0.6333, 0.8333, 0.9667)

Tablo 3. Calculated aggregated fuzzy decision matrix and the normalized form

Failure Modes	Fuzzy decision matrix			Normalized fuzzy-decision matrix		
	Severity	Occurrence	Detection	Severity	Occurrence	Detection
FM1	(3.66,5.66,7.66)	(9,10,10)	(5.66,7.33,10)	(0.36,0.56,0.76)	(0.9,1,1)	(0.56,0.73,1)
FM2	(5.66,7.66,9)	(9,10,10)	(5,7,8.66)	(0.56,0.76,0.9)	(0.9,1,1)	(0.5,0.7,0.86)
FM3	(9,10,10)	(9,10,10)	(3.66,5.66,7.33)	(0.9,1,1)	(0.9,1,1)	(0.36,0.56,0.73)
FM4	(4.33,6.33,8)	(7,9,10)	(3.66,5.33,6.66)	(0.43,0.63,0.8)	(0.7,0.9,1)	(0.36,0.53,0.66)
FM5	(6.33,8.33,9.66)	(7,9,10)	(5,7,9)	(0.63,0.83,0.96)	(0.7,0.9,1)	(0.5,0.7,0.9)
FM6	(1,3,5)	(5,7,9)	(7.66,9.33,10)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.76,0.93,1)
FM7	(7,9,10)	(5,7,9)	(2.33,4.33,6.33)	(0.7,0.9,1)	(0.5,0.7,0.9)	(0.23,0.43,0.63)
FM8	(1.66,3.66,5.66)	(3,5,7)	(7,9,10)	(0.16,0.36,0.56)	(0.3,0.5,0.7)	(0.7,0.9,1)
FM9	(2.33,4.33,6.33)	(1,3,5)	(6.33,8.33,9.66)	(0.23,0.43,0.63)	(0.1,0.3,0.5)	(0.63,0.83,0.96)
FM10	(8.33,9.66,10)	(1,3,5)	(1,3,5)	(0.83,0.96,1)	(0.1,0.3,0.5)	(0.1,0.3,0.5)
FM11	(6.33,8.33,9.66)	(1,3,5)	(4.33,6.33,8.33)	(0.63,0.83,0.96)	(0.1,0.3,0.5)	(0.43,0.63,0.83)
FM12	(2.33,4.33,6.33)	(1,3,5)	(5,7,8.66)	(0.23,0.43,0.63)	(0.1,0.3,0.5)	(0.5,0.7,0.86)
FM13	(1,3,5)	(1,3,5)	(8.33,9.66,10)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.83,0.96,1)

Considering the different weight of each criterion, the weighted normalized decision matrix is computed by multiplying the importance weights of evaluation criteria using Eq. (5). For example, the value of normalized fuzzy decision matrix in Table 3 is (0.366,0.566,0.766) with respect to severity criterion for FM1. This triangular fuzzy number is multiplied with the weights of the severity criterion (0.8333,0.9667,1) and obtained the values of (0.30,0.54,0.76) as seen Table 4.

Tablo 4. The weighted normalized decision matrix

Failure Modes	Severity	Occurrence	Detection
FM1	(0.30,0.54,0.76)	(0.33,0.56,0.76)	(0.35,0.61,0.96)
FM2	(0.47,0.74,0.9)	(0.33,0.56,0.76)	(0.31,0.58,0.83)
FM3	(0.75,0.96,1)	(0.33,0.56,0.76)	(0.23,0.47,0.70)
FM4	(0.36,0.61,0.8)	(0.25,0.51,0.76)	(0.23,0.44,0.64)
FM5	(0.52,0.80,0.96)	(0.25,0.51,0.76)	(0.31,0.58,0.87)
FM6	(0.08,0.29,0.5)	(0.18,0.39,0.69)	(0.48,0.77,0.96)
FM7	(0.58,0.87,1)	(0.18,0.39,0.69)	(0.14,0.36,0.61)
FM8	(0.13,0.35,0.56)	(0.11,0.28,0.53)	(0.44,0.75,0.96)
FM9	(0.19,0.41,0.63)	(0.36,0.17,0.38)	(0.40,0.69,0.93)
FM10	(0.69,0.93,1)	(0.36,0.17,0.38)	(0.06,0.25,0.48)
FM11	(0.52,0.80,0.96)	(0.36,0.17,0.38)	(0.27,0.52,0.80)
FM12	(0.19,0.41,0.63)	(0.36,0.17,0.38)	(0.31,0.58,0.83)
FM13	(0.08,0.29,0.5)	(0.36,0.17,0.38)	(0.52,0.80,0.96)

After obtaining the weighted normalized fuzzy decision matrix, (FPIS, A^*) and (FNIS, A^-) are determined using Eq. (6) as A^*=[(1,1,1),(1,1,1),(1,1,1)] and A^-=[(0,0,0),(0,0,0),(0,0,0)]. Afterwards, the distance of failure modes from the FPIS and FNIS is calculated. Value of 0.4971 as seen in Table 5 is distance of F1 from FPIS obtained by using Eq. (7). Similarly, the distance of same failure from FNIS is determined for severity (C1) as following.

$$d_1 = \sqrt{\frac{1}{3}[(1-0.305)^2+(1-0.547)^2+(1-0.766)^2]} = 0{,}4971$$

$$d_1 = \sqrt{\frac{1}{3}[(0-0.305)^2+(0-0.547)^2+(0-0.766)^2]} = 0.5719$$

The values of (d_i^*) and (d_i^-) are calculated utilizing Eqs. (8) and (9). In order to rank the failure modes based on their closeness to the FPIS and remoteness to the FNIS, the closeness coefficient is calculated using Eq.(10). For example, the value of 0.5669 for FM1 in Table 5 is calculated as CC_1= 1.8464 / (1.4104+1.8464) = 0. 5669.

At the end of the analysis, the ranking of failure modes is determined by comparing CC_i values. Alternative FMi is closer to the FPIS and further from FNIS as CC_i approaches to 1.

The ranking order of all alternatives is determined according to the descending order of CC_i;

$CC_3 > CC_5 > CC_2 > CC_1 > CC_7 > CC_4 > CC_{11} > CC_6 > CC_8 > CC_{10} > CC_9 > CC_{13} > CC_{12}$. The roller shooting mistake called FM3 has the highest priority to take precaution, followed by FM5, FM2, FM1, FM7, FM4, FM11, FM6, FM8, FM10, FM9, FM13, FM12 .

4. CONCLUSIONS

FMEA is a widely used engineering technique in industries by evaluating the failure in terms of risk factors named severity, occurrence and detection. While dealing with a large number of failure modes, classifying them into priority classes by experts allows managers to be focused on the most critical ones. Therefore, this indicates to be a multi-criteria sorting problem. However, in the literature, there are lacks of contributions on multi criteria decision making systems for the FMEA. Furthermore, in FMEA, the risk priority number of each failure mode is obtained by the multiplication of crisp values of the risk factors. Due to these criticisms in literature for risk priority number calculation, this paper considers a fuzzy TOPSIS approach for FMEA to deal with incomplete or uncertain information in real world problems. Moreover, in the textile sector, there is the paucity of research on fuzzy integrated techniques for FMEA analysis. In this context, another important contribution of this study is the application of FMEA analysis in knitting process in the textile sector using fuzzy TOPSIS.

As a result of this analysis; roller shooting mistake, oil stain, measurement inequality, touching error, number of hole, pattern error and yarn breakage determined as the most urgently important faults. Most of which are machine setting errors that arise usually due to the fact that employees work as careless and hasty. Also some faults are due to no regular maintenance on the machines. Employees should understand their tasks well and perform it carefully. To ensure this; the number and quality of the trainings at the factory must be increased and ensured their continuity. Another important issue is that the maintenance of the machines must be done regularly. These improvement activities for the determined faults in this study enable to increase customer satisfaction. The future research area on FMEA analysis using fuzzy integrated techniques needs to be expanded and complemented with empirical evidence.

Tablo 5. The distance of each supplier to FPIS and FNIS, closeness coefficient

Failure Modes	FPIS			d_i^*	FNIS			d_i^-	CC_i
	C_1	C_2	C_3		C_1	C_2	C_3		
FM1	0.4971	0.4800	0.4333	1.4104	0.5719	0.5825	0.6920	1.8464	0.5669
FM2	0.3443	0.4800	0.4715	1.2957	0.7262	0.5825	0.6171	1.9258	0.5978
FM3	0.1456	0.4800	0.5636	1.1891	0.9123	0.5825	0.5097	2.0045	0.6277
FM4	0.4467	0.5314	0.5844	1.5624	0.6179	0.5519	0.4714	1.6412	0.5123
FM5	0.2955	0.5314	0.4681	1.2950	0.7878	0.5519	0.6318	1.9715	0.6036
FM6	0.7290	0.6129	0.3241	1.6661	0.3372	0.4715	0.7692	1.5779	0.4864
FM7	0.2520	0.6129	0.6544	1.5194	0.8361	0.4715	0.4191	1.7268	0.5319
FM8	0.6698	0.7119	0.3528	1.7346	0.3941	0.3561	0.7513	1.5016	0.4640
FM9	0.6113	0.8159	0.3900	1.8172	0.4525	0.2430	0.7109	1.4065	0.4363
FM10	0.1804	0.8159	0.7543	1.7506	0.8861	0.2430	0.3163	1.4454	0.4523
FM11	0.2955	0.8159	0.5123	1.6237	0.7878	0.2430	0.5782	1.6090	0.4977
FM12	0.6113	0.8159	0.4715	1.8987	0.4525	0.2430	0.6171	1.3127	0.4088
FM13	0.7290	0.8159	0.2955	1.8404	0.3372	0.2430	0.7878	1.3680	0.4264

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