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Araştırma Makalesi / Research Article

RISK ANALYSIS APPLICATION IN AVIATION SECTOR WITH INTUITIONISTIC FUZZY TOPSIS METHOD

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Abstract
Failure Mode and Effects Analysis (FMEA) is one of the risk analysis techniques often used in many industries to recognize, assess, and avoid potential failures. Although FMEA is an analytical technique with strengths, such as helping to identify and reduce potential risks in processes and products, and being widely used, it has been criticized at some points. It is not easy to appoint a mathematical number between 1 and 10 to risk factors by the experts and decision makers who make the risk assessment. At this point, the use of linguistic variables offered by the intuitionistic fuzzy logic approach provides convenience to decision makers and increases the accuracy of risk assessments. This study purposes to assess the risks that may arise throughout the production process of a company operating in the aviation industry with FMEA. Considering the possibility that risk factors are ignored and risk priorities cannot be determined correctly, intuitionistic fuzzy logic approach is integrated into the study. For this purpose, risk factors have been weighted by experts. In problem solving, failures have been prioritized by experts with the support of linguistic variables by using the Intuitionistic Fuzzy TOPSIS method.
Keywords: Risk Analysis, Failure Prioritization, Failure Mode and Effects Analysis (FMEA), Intuitionistic Fuzzy Logic, TOPSIS
JEL Codes: C02, L61

HAVACILIK SEKTÖRÜNDE SEZGİSEL BULANIK TOPSIS YÖNTEMİYLE RİSK ANALİZİ UYGULAMASI

Öz
Hata Türü ve Etkileri Analizi (HTEA), birçok sektörde potansiyel hataları tanımlamak, değerlendirmek ve önlemek için sıklıkla kullanılan risk analizi tekniklerinden biridir. HTEA, süreçler ve ürünlerdeki potansiyel risklerin belirlenmesine ve azaltılmasına yardımcı olması ve yaygın olarak kullanılması gibi güçlü yönleri olan analitik bir teknik olmasına rağmen bazı noktalarda eleştirilmiştir. Risk değerlendirmesini yapan uzmanlar ve karar vericiler tarafından, risk faktörlerine 1 ile 10 arasında matematiksel bir sayı atamak kolay değildir. Bu noktada sezgisel bulanık mantık yaklaşımının sunduğu dilsel değişkenlerin kullanılması karar vericilere kolaylık sağlamakta ve risk değerlendirmelerinin doğruluğunu artırmaktadır. Bu çalışma, havacılık sektöründe faaliyet gösteren bir işletmenin üretim süreci boyunca ortaya çıkabilecek risklerini HTEA ile değerlendirmeyi amaçlamaktadır. Risk faktörlerinin göz ardı edilmesi ve risk önceliklerinin doğru belirlenememesi ihtimali göz önünde bulundurularak, çalışmaya sezgisel bulanık mantık yaklaşımı entegre edilmiştir. Bu amaçla risk faktörleri uzmanlar tarafından ağırlıklandırılmıştır. Problem çözümünde Sezgisel Bulanık TOPSIS yöntemi kullanılarak, dilsel değişkenlerin desteğiyle hatalar uzmanlar tarafından önceliklendirilmiştir.
Anahtar Kelimeler: Risk Analizi, Hata Önceliklendirme, Hata Türü ve Etkileri Analizi (HTEA), Sezgisel Bulanık Mantık, TOPSIS
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Introduction

Many businesses operating in various industries face risks and dangers for different reasons. Businesses which want to be in markets where competition is intense and, continue to hold onto, should conduct risks nicely. To conduct risks, it is necessary to identify and analysis risks. With the corrective and / or preventive actions planned according to the analysis results, risks and failures are eliminated or minimized. In this way, the owned resources are used much more effectively, reducing losses, and increasing efficiency.

In businesses that produce with high volume and strategic raw materials / materials, processes that begin with a mistake may consequence in huge damages if timely measures are not taken. Failures in production processes are difficult to compensate after reaching the customer and are costly (Zerenler & Karaboğa, 2014). Therefore, businesses that make production to order must keep their risks under control and avoid situations that may harm customer satisfaction.

The high failure rates that occur during the production stages cause economic inefficiency in terms of the business and lays the groundwork for a loss of trust in customers. Failure Mode and Effects Analysis (FMEA), which is one of the most reliable engineering techniques used in analysis and evaluating risks, is used to handle failures in business activities in terms of Occurrence, Severity and Detection. Failures are prioritized according to the Risk Priority Number (RPN) obtained by multiplying the failure occurrence, severity and detection values determined by the experts. FMEA approach alone may be insufficient in prioritizing failures. In this study, the results were analyzed by integrating the Intuitionistic Fuzzy Logic based TOPSIS approach into FMEA technique to eliminate the failures that arise in a company operating in the aviation sector and reduce the damage to the company.

The remained parts of the paper are as follows. Risk and risk management concepts are included in Section 1. The methodology and literature on FMEA are explained in Section 2. The case study is included in Section 3, while the discussions and conclusion are presented in the Section 4.

1. Risk Concept and Risk Management

The concept of risk is frequently used in various scientific fields such as banking, insurance, finance, decision making, management, trade and health. The concept of risk, which basically means the danger of loss or the possibility of being damaged, is also defined as uncertainty. Risk is an event that develops beyond expectations and can cause a negative situation. Risk is also expressed as the possibility of future situations, events or internal and external factors affecting the realization of goals and objectives.

In the OHSAS 18001 Occupational Health and Safety Management System, risk is expressed as the compound of the probability of occurrence of a dangerous event or exposure and the degree of severity of the injury or health impairment caused by the event or exposure, while in the ISO 31000 Risk Management System, it is described as the effect of uncertainty on goals.

Risk management is the determination, analysis and prioritization of risks in order to minimize the dangers that may occur during the activities of the businesses or to evaluate the opportunities that may arise in the best way. In general, risk management is the activities performed to reduce the risks to an acceptable level (Garvey, 2008).

Risk management focuses on uncertainties and analysis of results and takes care to resolve these results in favor of the business. The main purpose in risk management is to establish a balance between risks and opportunities. The risk management process is activated when the ability to meet targets becomes uncertain. It is aimed to pursue and check risks. The process of risk management consists of the following steps.

Identifying risks is the first step of the process of risk management. At this stage, potential threats and opportunities that may affect the process are identified. In the second stage, the possibilities, effects and consequences of the risks are presented. Risk analysis is performed by measuring the risks and effects that are likely to occur. In the third stage, risk sizes obtained from the risk analysis are graded, evaluated and put in order. Risk sizes are prioritized according to acceptable levels. In the fourth stage, it is necessary to plan remedial actions to eliminate the prioritized risks or bring them to the desired level. Corrective and preventive actions are planned toward from the highest risk value to the lowest risk value. At the last stage, the planned measures are put into practice and are reviewed to measure their effectiveness and remedial activities are revised when necessary.

2. Methodology

2.1. Failure Mode and Effects Analysis

In the 1960s, FMEA, which provided helpful outputs in the military and aviation industries, is one of the commonly used analytical tools and techniques to classify and remove potential or recognized failures and make risk management decisions to increase the reliability and safety of systems or processes and provide the necessary support (Shi et al., 2019). This method, which is based on the principle of identifying and correcting possible troubles before the production process, ensures the continuousness of high-level quality products by aiming to identify the core reasons of risks and reduce their impacts (Chang et al., 1999; Kahraman et al., 2013; Mızrak Özfırat, 2014; Ng et al., 2017). FMEA is a simple type of analysis used to reveal potential problems in systems and predict possible unwanted results. This method is inductive and answers the question what if problems occur in this part for each part of the system. This determines the situations involving significant problems that may occur in the parts of the system and how much the whole system will be affected when this problem is encountered (Üçkardeş & Ünal, 2012).

Early intervention and prevention of occurring or potential failures provide to decreasing system damages. FMEA, which serves to give priority to risks and mistakes; It contains of three factors: Occurrence, Severity, and Detection. Occurrence or state of occurrence of a failure Occurrence; the degree of damage to the environment or the customer when a failure occurs Severity; the chance of detecting the potential failure before reaching the customer or the degree of noticeability is expressed as Detection. Risk Priority Number (RPN = O * S * D) is obtained by multiplication the mathematical numbers of risk factors (Ünlükal et al., 2018). The numerical equivalent of each risk factor is between 1 and 10, so the RPN value is an integer between 1 and 1000. Corrective and preventive actions are planned by ordering the obtained RPN values in descending order.

2.2. Literature Review

There are many studies in the literature conducted by adopting the FMEA approach. Some of these studies are included in Table 1.

Table 1: *Literature Review*

Author(s)	Method(s)	Application Field
Faghih-Roohi et al. (2020)	Intuitionistic fuzzy TOPSIS+FMEA	Pharmaceutical shipment network
Balaraju et al. (2019)	Fuzzy FMEA	Mining operations
Lo & Liou (2018)	Best–worst method, Interval analysis, Grey relational analysis+FMEA	Smartphone manufacturing
Arabsheybani et al. (2018)	Fuzzy MOORA+FMEA	Sustainable supplier selection
Fattahi & Khalilzadeh (2018)	Extended fuzzy MULTIMOORA, Fuzzy AHP+FMEA	Steel industry
Maniram Kumar et al. (2018)	Fuzzy grey relational analysis+FMEA	LPG dispensing station
Şenel et al. (2018)	Intuitionistic fuzzy TOPSIS+FMEA	Maritime industry
Liu et al. (2018)	Entropy weight method+FMEA	Gas station supply chain
Yazdi (2018)	Intuitionistic fuzzy AHP, Intuitionistic fuzzy TOPSIS	Gas refinery
Guo et al. (2017)	Fuzzy AHP, QFD+FMEA	Shafting installation process
Huang et al. (2017)	Entropy method, TODIM+FMEA	Grinding wheel system
Certa et al. (2017)	ELECTRE TRI+FMEA	Dairy manufacturing industry
Wang et al. (2016)	IVIF-COPRAS, IVIF-ANP+FMEA	Hospital service
Zhou & Thai (2016)	Fuzzy and grey theory FMEA	Tanker equipment
Hu & Hsiao (2016)	Kano model+FMEA	Airline services
Liu et al. (2015)	Fuzzy AHP, Entropy method, Fuzzy VIKOR+FMEA	General anesthesia process
Jong et al. (2013)	Fuzzy FMEA	Edible bird nest production process
Kutlu & Ekmekçioğlu (2012)	Fuzzy AHP, Fuzzy TOPSIS+FMEA	Automotive industry
Liu & Tsai (2012)	Fuzzy ANP, QFD+FMEA	Construction industry
Yang et al. (2011)	Dempster–Shafer evidence theory+FMEA	Aircraft turbine rotor blade

Although FMEA is widely used in many areas, it is criticized for being limited due to the uncertainty and problems experienced in prioritizing the detected failure modes (Ben-Daya & Raouf, 1996; Bowles, 2004; Braglia et al., 2003; Chin et al., 2009; Gilchrist, 1993; Pillay & Wang, 2003; Sankar & Prabhu, 2001):

- Relative weights of O, S and D risk factors are not considered in traditional FMEA. The importance of these factors may not be equal for every situation.
- Some failure modes with different O, S and D numbers can have the same risk priority number.
- The formula used to determine the RPN value is open to discussion. There is no detailed justification in the literature that O, S, and D must be multiplication to calculate RPN.
- The RPN scale has a discrete structure, so it is difficult to derive a huge variety of values from 1 to 1000 from O, S and D risk factors.
- It is difficult to perceive the three factors numerically. In FMEA, a lot of information can be explained with linguistic variables as possible, important or very high.

Considering the criticisms, it is seen that FMEA has not been used alone in recent years. Instead, using it in integration with fuzzy logic and Multi Criteria Decision Making (MCDM) techniques increases the success of problem solving and provides a more realistic perspective. For this reason, the Intuitionistic Fuzzy TOPSIS method was used in the study to determine the importance of potential failures more clearly by removing the negative aspects mentioned above.

2.3. Intuitionistic Fuzzy TOPSIS

Professor Lotfi A. Zadeh (1965) laid the foundations of fuzzy logic by using the concept of Graded Sets. Zadeh has graded the memberships of the cluster members. In this way, he developed the concept of uncertainty and brought a new approach to the field of logic.

Atanassov (1986), on the other hand, brought a new perspective to fuzzy logic and focused on the functions of membership and non-membership. The degree of hesitancy is important as well as whether the elements belong to a set or not. This approach has been described as Intuitionistic Fuzzy Logic.

TOPSIS (The Technique for Order Preference by Similarity to Ideal Solution), which has been entered into the literature by Hwang and Yoon (1981), is a MCDM method used to determine the best candidate closest to the positive ideal solution and the furthest to the negative ideal solution in the alternative set. The purpose of TOPSIS, which has a simple use, is to maximize benefit criteria and minimize cost criteria. It is often used for solving complex decision-making problems.

There is a lot of controversy about the risk factors for the probability of occurrence of the failure (O), the severity of the failure (S), and the detection of the failure (D). Since linguistic evaluations are carried out by individuals in a relative manner, it has been assumed that the intuitionistic fuzzy (IF) set theory is suitable for dealing with the uncertainty of such evaluations and leading to more accurate results (Sayyadi Tooranloo et al., 2018). Ideally, risks should be assessed collectively and uncertainties in expert judgments to be used in the assessment should be minimized (Faghih-Roohi et al., 2020). For this reason, the group decision model proposed by choosing the TOPSIS technique in the study was used to assess risk factors and failure elements based on the FMEA in an IF environment.

The process steps of the method used in prioritizing failures are as follows (Sayyadi Tooranloo & Ayatollah, 2016):

Step 1: In the first stage, the weight of experts (decision makers) is calculated. Considering that there are k experts in the decision maker team, linguistic variables are used to calculate the weights of these experts and the IF numbers corresponding to these linguistic variables are shown in Table 2. Let $U_k = \{\mu_k, \nu_k, \pi_k\}$ be an Intuitionistic Fuzzy Number (IFN) belonging to an expert of *k*. The following equations are used to calculate the weight of the expert.

Table 2: *Linguistic Variables and IFN Used in Weighting Experts*

Linguistic Variables	IFN Equivalent
Very Important	(0.90, 0.10, 0.00)
Important	(0.75, 0.20, 0.05)
Average Important	(0.50, 0.45, 0.05)
Insignificant	(0.35, 0.60, 0.05)
Very Insignificant	(0.10, 0.90, 0.00)

Reference: (Sayyadi Tooranloo & Ayatollah, 2016)

$$\lambda_k = \frac{(\mu_k + \pi_k (\frac{\mu_k}{\mu_k + \nu_k}))}{\sum_{k=1}^{n} (\mu_k + \pi_k (\frac{\mu_k}{\mu_k + \nu_k}))} \text{ and } \sum_{k=1}^{n} \lambda_k = 1, k = (1, 2, ..., n) \quad (1)$$

If all experts are considered to be of same importance, the weight of expert *k* can be calculated by (2):

$$\lambda_k = \frac{1}{n} \text{ and } \sum_{k=1}^{n} \lambda_k = 1, k = (1, 2, ..., n) \quad (2)$$

Step 2: According to the experts' opinions, the aggregated IF decision matrix is created. Before the aggregation process, each expert's decision matrix must be established. For this, the linguistic variables shown in Tables 3, 4 and 5 are used. The IFWA operator is used to aggregate the decision matrices:

Table 3: *Linguistic Variables and IFN Used in the Assessment of Failure Occurrence*

Linguistic Variables	IFN Equivalent
Very High	(0.90, 0.10, 0.00)
High	(0.75, 0.20, 0.05)
Average	(0.50, 0.45, 0.05)
Low	(0.35, 0.60, 0.05)
Very Low	(0.10, 0.90, 0.00)

Reference: (Sayyadi Tooranloo & Ayatollah, 2016)

Table 4: *Linguistic Variables and IFN Used in the Assessment of Failure Severity*

Linguistic Variables	IFN Equivalent
Hazardous Without Warning	(1.00, 0.00, 0.00)
High-Risk Warnings	(0.90, 0.10, 0.00)
Very Much	(0.80, 0.10, 0.10)
Much	(0.70, 0.20, 0.10)
Average	(0.60, 0.30, 0.10)
Low	(0.50, 0.40, 0.10)
Very Low	(0.40, 0.50, 0.10)
Inconsiderable	(0.25, 0.60, 0.15)
Very Inconsiderable	(0.10, 0.75, 0.15)
None	(0.10, 0.90, 0.00)

Reference: (Sayyadi Tooranloo & Ayatollah, 2016)

Table 5: *Linguistic Variables and IFN Used in the Assessment of Failure Detection*

Linguistic Variables	IFN Equivalent
Absolutely Impossible	(1.00, 0.00, 0.00)
Very Unlikely	(0.90, 0.10, 0.00)
Unlikely	(0.80, 0.10, 0.10)
Very Low	(0.70, 0.20, 0.10)
Low	(0.60, 0.30, 0.10)
Average	(0.50, 0.40, 0.10)
Relatively High	(0.40, 0.50, 0.10)
High	(0.25, 0.60, 0.15)
Very High	(0.10, 0.75, 0.15)
Absolutely Possible	(0.10, 0.90, 0.00)

Reference: (Sayyadi Tooranloo & Ayatollah, 2016)

$$r_{ij} = IFWA_{\lambda}(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots, r_{ij}^{(l)}) = \lambda_1 r_{ij}^{(1)} \oplus \lambda_2 r_{ij}^{(2)} \oplus \lambda_3 r_{ij}^{(3)} \oplus \ldots \oplus \lambda_l r_{ij}^{(l)}$$
$$r_{ij} = [1 - \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(\nu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda_k} - \prod_{k=1}^{l}(\nu_{ij}^{(k)})^{\lambda_k}] \tag{3}$$

$r_{ij} = \left(\mu_{A_i}(x_j), \nu_{A_i}(x_j), \pi_{A_i}(x_j)\right)$ and $(i = 1,2,3,\ldots,m; j = 1,2,3,\ldots,n).$

The aggregated IF decision matrix is obtained as follows:

$$R = \begin{bmatrix} \mu_{FM_1}(O), \nu_{FM_1}(O), \pi_{FM_1}(O) & \mu_{FM_1}(S), \nu_{FM_1}(S), \pi_{FM_1}(S) & \mu_{FM_1}(D), \nu_{FM_1}(D), \pi_{FM_1}(D) \\ \mu_{FM_2}(O), \nu_{FM_2}(O), \pi_{FM_2}(O) & \mu_{FM_2}(S), \nu_{FM_2}(S), \pi_{FM_2}(S) & \mu_{FM_2}(D), \nu_{FM_2}(D), \pi_{FM_2}(D) \\ \vdots & & \\ \mu_{FM_n}(O), \nu_{FM_n}(O), \pi_{FM_n}(O) & \mu_{FM_n}(S), \nu_{FM_n}(S), \pi_{FM_n}(S) & \mu_{FM_n}(D), \nu_{FM_n}(D), \pi_{FM_n}(D) \end{bmatrix}$$

$$R = \begin{bmatrix} r_{1O} & r_{1S} & r_{1D} \\ r_{2O} & r_{2S} & r_{2D} \\ \vdots & \vdots & \vdots \\ r_{nO} & r_{nS} & r_{nD} \end{bmatrix} \tag{4}$$

Step 3: The weight of risk factors is calculated. Suppose $w_j^{(k)} = \left(\mu_j^{(k)}, \nu_j^{(k)}, \pi_j^{(k)}\right)$ is an IFN assigned to criterion j by expert k, then the weights of risk factors are determined through the IFWA operator as follows:

$$w_j = IFWA_{\lambda}(w_j^{(1)}, w_j^{(2)}, \ldots, w_j^{(l)}) = \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^{(2)} \oplus \lambda_3 w_j^{(3)} \oplus \ldots \oplus \lambda_l w_j^{(l)}$$
$$w_j = [1 - \prod_{k=1}^{l}(1-\mu_j^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(\nu_j^{(k)})^{\lambda_k}, \prod_{k=1}^{l}(1-\mu_j^{(k)})^{\lambda_k} - \prod_{k=1}^{l}(\nu_j^{(k)})^{\lambda_k}] \tag{5}$$

here $W = [w_1, w_2, w_3, \ldots, w_j], w_j = [\mu_j, \nu_j, \pi_j], (j = 1,2,\ldots,n).$

Step 4: Aggregated weighted IF decision matrix is determined. After finding the criterion weights (W) and the aggregated IF decision matrix, the aggregated weighted IF decision matrix is formed as follows (Atanassov, 1986):

$$R \otimes W = \left\{\left\langle c, \mu_{FM_i}(x).\mu_w(c), \nu_{FM_i}(c) + \nu_w(c) - \nu_{FM_i}(c).\nu_w(c) \mid c \in X \right\rangle\right\} \tag{6}$$

$$\pi_{FM_iW}(c) = 1 - \mu_{FM_i}(c).\mu_w(c) - \nu_{FM_i}(c) - \nu_w(c) + \nu_{FM_i}(c).\nu_w(c) \tag{7}$$

$$R' = \begin{bmatrix} \mu_{FM_1W}(O), \nu_{FM_1W}(O), \pi_{FM_1W}(O) & \mu_{FM_1W}(S), \nu_{FM_1W}(S), \pi_{FM_1W}(S) & \mu_{FM_1W}(D), \nu_{FM_1W}(D), \pi_{FM_1W}(D) \\ \mu_{FM_2W}(O), \nu_{FM_2W}(O), \pi_{FM_2W}(O) & \mu_{FM_2W}(S), \nu_{FM_2W}(S), \pi_{FM_2W}(S) & \mu_{FM_2W}(D), \nu_{FM_2W}(D), \pi_{FM_2W}(D) \\ \vdots & \vdots & \vdots \\ \mu_{FM_nW}(O), \nu_{FM_nW}(O), \pi_{FM_nW}(O) & \mu_{FM_nW}(S), \nu_{FM_nW}(S), \pi_{FM_nW}(S) & \mu_{FM_nW}(D), \nu_{FM_nW}(D), \pi_{FM_nW}(D) \end{bmatrix} \tag{8}$$

$$R' = \begin{bmatrix} r'_{1O} & r'_{1S} & r'_{1D} \\ r'_{2O} & r'_{2S} & r'_{2D} \\ \vdots & \vdots & \vdots \\ r'_{nO} & r'_{nS} & r'_{nD} \end{bmatrix} \tag{9}$$

$r'_{ij} = (\mu'_{ij}, \nu'_{ij}, \pi'_{ij}) = (\mu_{FMW}(c), \nu_{FMW}(c), \pi_{FMW}(c))$ is an element of the aggregated weighted IF decision matrix.

Step 5: Based on IFN, positive and negative ideal solution points are determined. Assuming that J_1 expresses the utility criterion and J_2 expresses the cost criterion, FM^+ represents the IF positive ideal solution, while FM^- represents the IF negative ideal solution. FM^+ and FM^- are expressed in the following equations:

$FM^+ = ((\mu_{FM^+W}(c_j), \nu_{FM^+W}(c_j), \pi_{FM^+W}(c_j))$ and $FM^- = ((\mu_{FM^-W}(c_j), \nu_{FM^-W}(c_j), \pi_{FM^-W}(c_j))$ (10)

$$\mu_{FM^+W}(c_j) = \left(\left\langle \max_i \mu_{FM^+W}(c_j) \mid j \in J_1 \right\rangle, \left\langle \min_i \mu_{FM^+W}(c_j) \mid j \in J_2 \right\rangle\right) \tag{11}$$

$$\nu_{FM^+W}(c_j) = \left(\left\langle \min_i \nu_{FM^+W}(c_j) \mid j \in J_1 \right\rangle, \left\langle \max_i \nu_{FM^+W}(c_j) \mid j \in J_2 \right\rangle\right) \tag{12}$$

$$\mu_{FM^-W}(c_j) = \left(\left\langle \min_i \mu_{FM^-W}(c_j) \mid j \in J_1 \right\rangle, \left\langle \max_i \mu_{FM^-W}(c_j) \mid j \in J_2 \right\rangle\right) \tag{13}$$

$$\nu_{FM^-W}(c_j) = \left(\left\langle \max_i \nu_{FM^-W}(c_j) \mid j \in J_1 \right\rangle, \left\langle \min_i \nu_{FM^-W}(c_j) \mid j \in J_2 \right\rangle\right) \tag{14}$$

Step 6: Distance measurements are calculated using IF sets. In this step, the Euclidean distance formula is used to measure the distances. For each point, the distances from the IF positive ideal solution point (S^+) and the IF negative ideal solution point (S^-) are calculated as follows:

$$S_i^+ = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[(\mu_{FM_iW}(c_j) - \mu_{FM^+W}(c_j))^2 + (\nu_{FM_iW}(c_j) - \nu_{FM^+W}(c_j))^2 + (\pi_{FM_iW}(c_j) - \pi_{FM^+W}(c_j))^2\right]} \tag{15}$$

$$S_i^- = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[(\mu_{FM_iW}(c_j) - \mu_{FM^-W}(c_j))^2 + (\nu_{FM_iW}(c_j) - \nu_{FM^-W}(c_j))^2 + (\pi_{FM_iW}(c_j) - \pi_{FM^-W}(c_j))^2\right]} \tag{16}$$

Step 7: The relative closeness coefficient (CC_i) required for the intuitionistic ideal solution is calculated individually. CC_i can be calculated as follows:

$$CC_i = \frac{S_i^-}{S_i^- + S_i^+}, \quad 0 \le CC_i \le 1 \tag{17}$$

Step 8: The calculated relative closeness coefficients are ranked in descending order. This ranking also expresses risk priority.

3. Case Study

The study was carried out in Eskişehir (in Turkey) in a company that operates in the field of precision aircraft engine parts and structural parts manufacturing, engineering, fixture and tool design manufacturing, special processes and quality control, and machining for the aviation industry.

The company, which has a machine park consisting of 21 vertical lathes, 27 horizontal lathes, 8 milling machines and 4 precision measuring devices and more than 200 employees, is one of the high-capacity companies operating in the sector for more than 25 years. Factors such as wide machine park, high number of products and employees, flexible and variable customer demands increase the complexity of the works in the company. Due to increasing customer complaints, rework part rates, delayed deliveries and rising costs, the company wanted to solve the problems it faced. The company, which could not find the substantial solutions within its own structure, wanted to stop the growth of the problems by taking external consultancy services. It has been determined that most of the problems occur in parts that are ignored during the production process, but mostly produced. In order to reduce the problems in a short time, studies have started with the product that poses a high risk. With the precautions to be taken according to the results of the analysis to be made, firstly, an improvement will be provided throughout the part dealt with, and then these precautions will be implemented across all products. Thus, the company wants to take an important step in achieving its goals and realizing its missions by ensuring customer satisfaction with sustainable production assurance. Due to these demands, cooperation was established with the company and necessary analyzes were made. The main purpose of this study is to identify the risks / failures that occur or may occur along the production process of a critical aircraft engine part produced in the company, and to realize a safer production process by eliminating these risks / failures.

It is aimed to reduce the failures and increase the quality performance by defining the failures that may occur along the manufacturing process. For this purpose, a team of two experts working as a quality engineer in the quality department has been formed. Using the failure records and the experiences of the team members, the product with the most problems in the production process and the problems that occurred during the manufacturing process of this product were determined. Risk analysis studies were evaluated with the IF TOPSIS method, and failure priorities were determined.

Shaft is one of the most produced products in the company and 2 vertical and 1 horizontal turning lathes are allocated only for this product, without changing the turning program. Shaft is one of the aircraft engine parts and is critical. Therefore, it is not possible to estimate the value of any failure that may occur. Considering all these features, it is inevitable to carry out risk analysis on this product.

Risk analysis does not only ensure that the customer receives fault-free parts; at the same time, by producing the right product at the first time, direct labor time and costs are reduced, the cycle time of the product is reduced, the consumables used are reduced, the rework times are reduced and the capacity utilization rate is increased.

3.1. Risk Analysis Application

To make the risk assessment, first, the failures that may occur in the production process of the product named HPT AFT SHAFT must be defined. The failures and their effects are specified in Table 6.

Table 6: *Definition of Failures Occurring in the Factory and Failures Effects*

Failure Modes	Failure	Failure Description	Failure Effect
FM1	Measure Failure	Measures out of tolerance limits	Part does not fit properly
FM2	Surface Defects	Failures caused by felt, cutting and measuring tool, fixture seating point marks	Affects product function and appearance
FM3	Dent	Cavities in the part due to various reasons	Surface quality deteriorates, risk of edge breakage increases, product function is affected
FM4	Crushed	Cracks, breaks or deep marks on some parts of the product	The functionality of the product deteriorates, and the desired properties cannot be obtained
FM5	Set	Failure to machine the part correctly due to burr or insert failures during machining	The function of the final product is affected, and the desired product cannot be obtained
FM6	Non-Occurring Measure	The absence of features such as edges, corners, angles, etc.	The desired product cannot be obtained

After failures are identified, the steps required for risk analysis application are as follows:

Step 1: Since the weight of the experts is considered equal, the weight is calculated according to (2).

The weight of each expert is determined as $\lambda_k = \frac{1}{2} = 0,50$.

Step 2: Expert opinions are determined according to the linguistic variables shown in Tables 3, 4 and 5 and the aggregated IF decision matrix is formed. The opinions of the experts are shown in Table 7.

Table 7: *Risk Evaluation According to Expert Opinions*

Expert -1	Occurrence	Severity	Detection
FM1	Very High	Very Much	Low
FM2	Low	Very Inconsiderable	Unlikely
FM3	Average	Inconsiderable	Average
FM4	Very Low	Inconsiderable	Average
FM5	Average	Very Low	Average
FM6	Average	Much	Unlikely
Expert -2	**Occurrence**	**Severity**	**Detection**
FM1	Very High	High-Risk Warnings	Low
FM2	Average	Very Low	Average
FM3	Average	Low	Relatively High
FM4	Low	Low	Relatively High
FM5	Very Low	Much	Very High
FM6	Low	Very Much	Very Unlikely

Evaluations made with linguistic variables are transformed into IFN as indicated in Table 8.

Tablo 8: *Decision Matrix*

Expert -1		O			S			D	
FM1	0.9	0.1	0	0.8	0.1	0.1	0.6	0.3	0.1
FM2	0.35	0.6	0.05	0.1	0.75	0.15	0.8	0.1	0.1
FM3	0.5	0.45	0.05	0.25	0.6	0.15	0.5	0.4	0.1
FM4	0.1	0.9	0	0.25	0.6	0.15	0.5	0.4	0.1
FM5	0.5	0.45	0.05	0.4	0.5	0.1	0.5	0.4	0.1
FM6	0.5	0.45	0.05	0.7	0.2	0.1	0.8	0.1	0.1
Expert -2		O			S			D	
FM1	0.9	0.1	0	0.9	0.1	0	0.6	0.3	0.1
FM2	0.5	0.45	0.05	0.4	0.5	0.1	0.5	0.4	0.1
FM3	0.5	0.45	0.05	0.5	0.4	0.1	0.4	0.5	0.1
FM4	0.35	0.6	0.05	0.5	0.4	0.1	0.4	0.5	0.1
FM5	0.1	0.9	0	0.7	0.2	0.1	0.7	0.2	0.1
FM6	0.35	0.6	0.05	0.8	0.1	0.1	0.9	0.1	0

Expert opinions are aggregated using the IFWA operator.

Tablo 9: *Decision Matrix*

		O			S			D	
FM1	0.900	0.100	0.000	0.859	0.100	0.041	0.600	0.300	0.100
FM2	0.430	0.520	0.050	0.265	0.612	0.122	0.684	0.200	0.116
FM3	0.500	0.450	0.050	0.388	0.490	0.122	0.452	0.447	0.101
FM4	0.235	0.735	0.030	0.388	0.490	0.122	0.452	0.447	0.101
FM5	0.329	0.636	0.034	0.576	0.316	0.108	0.613	0.283	0.104
FM6	0.430	0.520	0.050	0.755	0.141	0.104	0.859	0.100	0.041

Step 3: The weight of risk factors is calculated to weight the decision matrix.

Table 10: *Experts' Evaluations of Risk Factors*

	O	S	D
Expert -1	High	Very high	Average
Expert -2	Very high	Very high	High

Table 11: *Risk Factors Weights*

	O			S			D		
W	0.842	0.141	0.017	0.900	0.100	0.000	0.646	0.300	0.054

Step 4: The aggregated weighted IF decision matrix is determined according to the weights of the risk factors.

Table 12: *Aggregated Weighted Decision Matrix*

	O			S			D		
FM1	0.758	0.227	0.015	0.773	0.190	0.037	0.388	0.510	0.102
FM2	0.362	0.588	0.051	0.239	0.651	0.110	0.442	0.440	0.118
FM3	0.421	0.528	0.051	0.349	0.541	0.110	0.292	0.613	0.095
FM4	0.198	0.772	0.030	0.349	0.541	0.110	0.292	0.613	0.095
FM5	0.277	0.688	0.035	0.518	0.385	0.097	0.396	0.498	0.106
FM6	0.362	0.588	0.051	0.680	0.227	0.093	0.555	0.370	0.075

Step 5: Based on IFN, positive and negative ideal solution points are determined.

Table 13: *Positive and Negative Ideal Solutions*

	O			S			D		
FM^+	0.758	0.227	0.015	0.773	0.190	0.037	0.555	0.370	0.075
FM^-	0.198	0.772	0.030	0.239	0.651	0.110	0.292	0.613	0.095

Step 6: Distance measurements are calculated using IF sets.

Step 7: The relative closeness coefficient (CC_i) required for the intuitionistic ideal solution is calculated.

Table 14. *Distance Measures and Closeness Coefficients*

	S_i^+	S_i^-	CC_i	Rank
FM1	0.090	0.435	0.829	1
FM2	0.368	0.138	0.273	5
FM3	0.327	0.150	0.314	4
FM4	0.418	0.064	0.132	6
FM5	0.314	0.176	0.360	3
FM6	0.224	0.307	0.578	2

Step 8: In Table 14, the distance of the values belonging to each failure mode to the positive and negative ideal solution set is calculated and arranged according to the closeness coefficients in descending order. This order also refers to the order of risk priority. Accordingly, the highest risk priority is the measurement failure with FM1 code. This is followed by FM6, FM5, FM3, FM2 and FM4 respectively.

4. Discussions and Conclusions

FMEA is an effective method for designing and planning product and process by determining risks in various processes and preventing or reducing their effects at early stages. In traditional FMEA, RPN values are obtained by multiplication O, S, D and the degree of criticality is determined. However, this practice has some disadvantages such as multiplying different values of risk factors and obtaining the same RPN value without considering the weights of risk factors.

Despite advances in risk assessment, methods such as FMEA have gained wide-ranging applicability due to their simplicity and less time expenditure. On the other hand, FMEA method is criticizes and FMEA application is narrow due to its inherent uncertainty, various restrictions and difficult capture of objectivity. Risk assessment in FMEA is a specific complex task that is often performed with the experience and intuition of team members.

The integrated approach proposed in this study, which aims to eliminate critical failures in a business operating in the aviation industry, strategically evaluates the link established between risk analysis and MCDM methods. The approach starts from the need to define all of the risks through FMEA to analyze the risk factors of the system under study in depth. The IF TOPSIS method is used to prioritize the failures according to various evaluation criteria to rank the importance of all failure modes. IF TOPSIS is powerful at the same time in directing data uncertainty as it uses IFN. Risk factors were weighted by the aggregation of collective decisions made by a group of experts. This application was carried out in prospect of that risk factors may not have the same weight. Values of different weighted risk factors estimated by IF expressions are given based on expert judgment. This is an important progress in FMEA area, as giving distinctive weights to factors using IF logic adds a new perspective to FMEA. Then, IF TOPSIS was applied to analysis possible failure modes and rank them according to risk priorities, and linguistic variables were used.

The results obtained from this study are both guiding and warning to other companies operating in the same / similar sector, as well as improving the production processes in other products of the company. Companies that realize the risks / failures that have not yet occurred in their processes can easily take precautions or apply to written studies / research reports such as this to solve similar problems. Thus, the risks either never occur or cause minimal damage.

There are several important issues that limit this study. Expert opinions in calculating RPN or determining the weights of risk factors affect the priority order of failure modes. It should be considered that if there is any change in the evaluations of decision makers, the order of priority will change. Therefore, repeating the study with different experts and examining the consequence of the changes will contribute to the literature.

A recommendation has been provided against the limitations expressed in the paragraph above. Based on the company examined in this study, it is thought that it will be beneficial to restructure the study by increasing the sample size in the cluster formed by the companies operating in the aviation sector and to examine the results. It can be aimed to produce solutions to the problems that occur on a sectoral basis. In this way, problems can be more easily generalized and dealt with in a radical way and permanent solutions are developed.

Other suggestion to be presented for the development of the proposed method is to use MCDM techniques such as AHP or ANP in determining the risk factor weights that can cause objective results in the process of evaluating failure modes. It may be important to what extent the weights determined in this way will affect the result. Another suggestion is to use other MCDM methods in problem solving in addition to TOPSIS in risk assessment of failure modes and to look at the differences in risk priority order.

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References

Arabsheybani, A., Paydar, M. M., & Safaei, A. S. (2018). An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk. *Journal of Cleaner Production*, *190*, 577–591.

Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, *20*(1), 87–96.

Balaraju, J., Govinda Raj, M., & Murthy, C. S. (2019). Fuzzy-FMEA risk evaluation approach for LHD machine-A case study. *Journal of Sustainable Mining*, *18*(4), 257–268.

Ben-Daya, M., & Raouf, A. (1996). A revised failure mode and effects analysis model. *International Journal of Quality and Reliability Management*, *13*(1), 43–47.

Bowles, J. B. (2004). An assessment of RPN prioritization in a failure modes effects and criticality analysis. *Journal of the IEST*, *47*, 51–56.

Braglia, M., Frosolini, M., & Montanari, R. (2003). Fuzzy criticality assessment model for failure modes and effects analysis. *International Journal of Quality and Reliability Management*, *20*(4), 503–524.

Certa, A., Enea, M., Galante, G. M., & La Fata, C. M. (2017). ELECTRE TRI-based approach to the failure modes classification on the basis of risk parameters: An alternative to the risk priority number. *Computers and Industrial Engineering*, *108*, 100–110.

Chang, C. L., Wei, C. C., & Lee, Y. H. (1999). Failure mode and effects analysis using fuzzy method and grey theory. *Kybernetes*, *28*(9), 1072–1080.

Chin, K. S., Wang, Y. M., Ka Kwai Poon, G., & Yang, J. B. (2009). Failure mode and effects analysis using a group-based evidential reasoning approach. *Computers and Operations Research*, *36*(6), 1768–1779.

Faghih-Roohi, S., Akcay, A., Zhang, Y., Shekarian, E., & de Jong, E. (2020). A group risk assessment approach for the selection of pharmaceutical product shipping lanes. *International Journal of Production Economics*, *229*(April), 1–13.

Fattahi, R., & Khalilzadeh, M. (2018). Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. *Safety Science*, *102*(October 2017), 290–300.

Garvey, P. R. (2008). *Analytical methods for risk management.* New York: Chapman and Hall/CRC.

Gilchrist, W. (1993). Modelling failure modes and effects analysis. *International Journal of Quality & Reliability Management*, *10*(5), 16–23.

Guo, Q., Sheng, K., Wang, Z., Zhang, X., Yang, H., & Miao, R. (2017). Research on element importance of shafting installation based on QFD and FMEA. *Procedia Engineering*, *174*, 677–685.

Hu, K. C., & Hsiao, M. W. (2016). Quality risk assessment model for airline services concerning Taiwanese airlines. *Journal of Air Transport Management*, *53*, 177–185.

Huang, J., Li, Z., & Liu, H. C. (2017). New approach for failure mode and effect analysis using linguistic distribution assessments and TODIM method. *Reliability Engineering and System Safety*, *167*(January), 302–309.

Hwang, C. L. & Yoon, K. (1981). *Multiple attributes decision making methods and applications*. Berlin: Springer.

Jong, C. H., Tay, K. M., & Lim, C. P. (2013). Application of the fuzzy failure mode and effect analysis methodology to edible bird nest processing. *Computers and Electronics in Agriculture*, *96*, 90–108.

Kahraman, C., Kaya, I., & Şenvar, Ö. (2013). Healthcare failure mode and effects analysis under fuzziness. *Human and Ecological Risk Assessment*, *19*(2), 538–552.

Kutlu, A. C., & Ekmekçioğlu, M. (2012). Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP. *Expert Systems with Applications*, *39*(1), 61–67.

Liu, H. C., You, J. X., You, X. Y., & Shan, M. M. (2015). A novel approach for failure mode and effects analysis using combination weighting and fuzzy VIKOR method. *Applied Soft Computing Journal*, *28*, 579–588.

Liu, H. T., & Tsai, Y. lin. (2012). A fuzzy risk assessment approach for occupational hazards in the construction industry. *Safety Science*, *50*(4), 1067–1078.

Liu, Y., Kong, Z., & Zhang, Q. (2018). 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*(5), 325–330.

Lo, H. W., & Liou, J. J. H. (2018). A novel multiple-criteria decision-making-based FMEA model for risk assessment. *Applied Soft Computing Journal*, *73*, 684–696.

Maniram Kumar, A., Rajakarunakaran, S., Pitchipoo, P., & Vimalesan, R. (2018). Fuzzy based risk prioritisation in an auto LPG dispensing station. *Safety Science*, *101*(May 2017), 231–247.

Mızrak Özfırat, P. (2014). Bulanık önceliklendirme metodu ve hata türü ve etkileri analizini birleştiren yeni bir risk analizi yöntemi. *Gazi Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, *29*(4), 755–768.

Ng, W. C., Teh, S. Y., Low, H. C., & Teoh, P. C. (2017). The integration of FMEA with other problem solving tools: A review of enhancement opportunities. *Journal of Physics: Conference Series*, *890*(1).

Pillay, A., & Wang, J. (2003). Modified failure mode and effects analysis. *Reliability Engineering & System Safety*, *79*, 69–85.

Sankar, N. R., & Prabhu, B. S. (2001). Modified approach for prioritization of failures in a system failure mode and effects analysis. *International Journal of Quality & Reliability Management*, *18*(3), 324–335.

Sayyadi Tooranloo, H., Ayatollah, A. S., & Alboghobish, S. (2018). Evaluating knowledge management failure factors using intuitionistic fuzzy FMEA approach. *Knowledge and Information Systems*, *57*(1), 183–205.

Sayyadi Tooranloo, H., & Ayatollah, A. S. (2016). A model for failure mode and effects analysis based on intuitionistic fuzzy approach. *Applied Soft Computing Journal*, *49*, 238–247.

Şenel, M., Şenel, B., & Havle, C. A. (2018). Risk analysis of ports in maritime industry in Turkey using FMEA based intuitionistic fuzzy TOPSIS approach. *ITM Web of Conferences*, *22*, 01018.

Shi, S., Fei, H., & Xu, X. (2019). Application of a FMEA method combining interval 2-tuple linguistic variables and grey relational analysis in preoperative medical service process. *IFAC-PapersOnLine*, *52*(13), 1242–1247.

Üçkardeş, İ., & Ünal, D. (2012). Risk analizi ve havacılık sektöründe kaza risklerinin incelenmesi. *Ç.Ü Fen ve Mühendislik Bilimleri Dergisi*, *27*(2), 174–181.

Ünlükal, C., Şenel, M., & Şenel, B. (2018). Risk assessment with failure mode and effects analysis and grey relational analysis method in plastic injection process. *ITM Web of Conferences*, *22*, 01023.

Wang, L. E., Liu, H. C., & Quan, M. Y. (2016). Evaluating the risk of failure modes with a hybrid MCDM model under interval-valued intuitionistic fuzzy environments. *Computers and Industrial Engineering*, *102*, 175–185.

Yang, J., Huang, H. Z., He, L. P., Zhu, S. P., & Wen, D. (2011). Risk evaluation in failure mode and effects analysis of aircraft turbine rotor blades using Dempster-Shafer evidence theory under uncertainty. *Engineering Failure Analysis*, *18*(8), 2084–2092.

Yazdi, M. (2018). Risk assessment based on novel intuitionistic fuzzy-hybrid-modified TOPSIS approach. *Safety Science*, 110(March), 438–448.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*, 338–353.

Zerenler, M., & Karaboğa, K. (2014). Müşteri memnuniyetinin sağlanmasında hataların önlenmesine yönelik üretim odaklı bir bakış açısı: Poka-Yoke sistemleri. *Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, Dr. Mehmet YILDIZ Özel Sayısı, 263–276.

Zhou, Q., & Thai, V. V. (2016). Fuzzy and grey theories in failure mode and effect analysis for tanker equipment failure prediction. Safety Science, *83*, 74–79.