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FMEA ANALYSIS IN MECHANICAL INSTALLATION PROJECT BASED ON BEST WORST AND NEUTROSOPHIC AHP INTEGRATED MODEL

MEKANİK TESİSAT PROJELERİNDE BEST WORST VE NÖTROSOFİK AHP
ENTEĞRE MODELİYLE HATA TÜRÜ VE ETKİLERİ ANALİZİ

Melih YÜCESAN¹

Abstract

Failure mode and effect analysis (FMEA) is a risk assessment tool that aims to improve security, identify, evaluate, and minimize failure modes in systems, designs, products, processes, or projects. The risk priority number (RPN) is the fundamental assessment criteria for FMEA-based risk assessment practices. The determination of RPN is based on the risk factors like occurrence (O), severity (S), and detection (D), should be calculated appropriately. However, the traditional RPN calculation method has been heavily criticized for many reasons, such as not considering the weight of the risk factors. To overcome this disadvantage of the traditional FMEA method, this paper proposes the FMEA model with Best Worst method (BWM) and Neutrosophic analytic hierarchy process (NAHP) integrated model for mechanical installation project. The weights of FMEA parameters S, O, and D are calculated by BWM method, which provides highly consistent pairwise comparison and reliable results. Then nine failure modes are evaluated in terms of S, O, and D parameters by NAHP method. Risk priority indexes are computed for determining the risk priorities of the failure modes. Finally, preventive measures have been proposed for the identified failure modes.

Keywords: Best Worst method, Failure Modes and Effects Analysis, Neutrosophic Set, Mechanical Installation Project

Öz

Hata türü ve etkileri analizi (FMEA), sistemlerdeki, tasarımlardaki, ürünlerdeki, projelerdeki veya projelerdeki güvenliği iyileştirmeyi, tanımlamayı, değerlendirmeyi ve en aza indirmeyi hedefleyen bir risk değerlendirme aracıdır. Risk önceliği numarası (RPN), FMEA bazlı risk değerlendirme uygulamaları için temel değerlendirme kriteridir. RPN'nin oluşum (O), şiddeti (S) ve tespiti (D) gibi risk faktörlerine dayanarak uygun şekilde hesaplanmalıdır. Bununla birlikte, geleneksel RPN hesaplama yöntemi, risk faktörlerinin ağırlığını göz önünde bulundurmamak gibi birçok nedenden dolayı ağır biçimde eleştirilmiştir. Geleneksel FMEA yönteminin bu dezavantajının üstesinden gelmek için, bu makale, mekanik tesisat projeleri için Best Worst method (BWM) ve Nötrosifik analitik hiyerarşi süreci (NAHP) ile entegre modelini içeren FMEA modelini önermektedir. FMEA parametresi S, O ve D'nin ağırlıkları, BWM yöntemiyle hesaplanır ve bu da, tutarlı bir şekilde ikili karşılaştırma ve güvenilir sonuçlar sağlar. Daha sonra dokuz arıza modu, NAHP metodu ile S, O ve D parametreleri açısından değerlendirilir. Arıza modlarının risk önceliklerini belirlemek için risk öncelik endeksleri hesaplanır. Son olarak, belirlenen arıza modları için önleyici tedbirler önerilmiştir.

Anahtar Kelimeler: Best Worst metodu, Hata türü ve etkileri analizi, Nötrosifik set, mekanik tesisat projeleri,

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1. INTRODUCTION

Risk can be evaluated as a natural result of production or operation activities. The risks can never be reduced to zero. It is aimed to reduce the risks to acceptable levels (Gul and Guneri, 2016; Vahdani et al. 2015). Zhi-qiang and Ya-mei (2016) defined the risks as the probability of occurrence of dangerous situations. The success of the risk assessment depends directly on the method used. Development of risk assessment methods is the most essential part of current studies. (Ouédraogo et al. 2011; Jannadi and Almishari 2003). Risk management in project management is directly related to the success of the project. Failure to carry out effective risk management may result in projects exceeding the budget, failure of the project calendar, failure to set targets or exhibit any combination of these troubles (Carbone and Tippett 2004).

It is vital to detect the fault when the system fails quickly. It is always more advantageous to take preventive measures before an error occurs. When more than one system is used together, error detection can be challenging, and error detection is even more difficult in newly installed systems (Peeters et al. 2018).

Many methods have been used to evaluate the safety of structures. There are three types of methods commonly used in the literature: qualitative, quantitative, and combined qualitative-quantitative (Pinto, 2014; Leu and Chang, 2013). Qualitative risk analysis is carried out with the knowledge and translations of the experts. However, since the failure modes occur differently, assigned risk levels for the failure modes may be subjective, which increases the probability of assessment distortion. Quantitative analysis is based on actual observed data and is more objective (Ouédraogo et al. 2011; Jannadi and Almishari, 2003). There are various quantitative techniques for evaluating risk such as Monte Carlo Simulation (Schuhmacher et. al. 2001; Amigun et. al. 2011) Event Trees (Linder et. al.; Vilchez and Casal 2011) Fault Trees (Lindhe et. al. 2009; Menten and Helvacioğlu 2011; Leu and Chang, 2013; Fink et al., 2014; Johnston, 2000), FMEA (Carlsson 2004; Zhang and Chu 2011; Carbone and Tippett, 2004), Fuzzy set (Misra and Weber 1990; Hui et. al. 2009), game theory (Miao et. al. 2010; Turskis et. al. 2009), multicriteria verbal analysis (Ustinovichius, 2009), Grey Systems (Zavadskas et. al. 2010).

This study proposed FMEA based a qualitative-quantitative BWM and NAHP integrated approach to determine the importance of failure modes. We aim to eliminate the shortcomings of the risk prioritization of classical FMEA. FMEA is a technique used to define, identify and eliminate failure modes, in process, products or projects designs and defined RPN as the probability of the occurrence (O), severity (S) and detection (D) of the failure (Stamatis 2003; Jiang et al. 2017). In the real application, there are lots of FMEA problems which contain imperfect, ambiguous, and imprecise information. Some of the project's risk assessment studies in FMEA-based can be listed as follows:

Singh and Sarkar (2017) proposed a model for significant activities of the elevated corridor metro rail project by Fuzzy FMEA. They used Expected Value Method and Fuzzy FMEA together and claimed to launch girder and necessary span activities hazardous in a metro project. Carbone and Tippett (2004) proposed a new method called (RFMEA) which modification of FMEA. The proposed approach has been implemented electronics industry by adding detection parameters of the failure. Abdelgawad and Fayek (2010) in order to overcome Tradition FMEA limitation used fuzzy AHP in the construction industry. A real application is made to verify the proposed model. After determining significant risks, preventive measures were determined. Zeng et al. (2010) propose a FMEA based risk management procedure for occupational health and safety under the integrated management system. Result of the proposed model indicates that five significant potential risks graded to

be unacceptable. Preventive measures are recommended for these risks. Mohammadi and Tavakolan (2013) used AHP in order to overcome traditional FMEA limitations in project risk management field. They used likelihood, impact, and detection parameter by means using expert judgments. Also, the feedback on the proposed model received from decision makers. Razaque et al. (2012) proposed to project scheduling approach for schedule and risk management. They used Monte Carlo simulation in order to compute the total time of project. The proposed approach also aims to control risk mitigation by using event tree analysis and fault tree analysis.

Traditional AHP cannot reflect uncertainties in the decision-making process. To overcome the limitation of AHP method, AHP integrated with neutrosophic sets to assign weights of risk parameters in FMEA. Smarandache (2002) proposed that neutrosophic sets reflect uncertainty and ambiguity in real-world problems better than standard fuzzy sets theory. It has truthiness, indeterminacy, and falsity parameters for decision-making. Neutrosophic sets have some advantages as follows (Abdel-Basset et al. 2018a; 2017): (i) It provides an indeterminacy degree that helps experts to make their determination more precisely. (ii) It signifies the extent of decision makers disagreements AHP is a widely used MCDM method developed by Saaty (1990). It represents the MCDM problem hierarchically including a goal, criteria, and alternatives. AHP recommends weighting criteria and ranking one for alternative options (Gul, 2018). Some of the literature on NAHP are listed below.

Abdel-Basset (2018) has proposed a new approach for sustainable supplier selection. The proposed neurotropic set will be used in this approach. So you will be able to cope with unclear and inconsistent information in the real world. Pramanik (2018) proposed a model by using single-valued neutrosophic number and ranking strategy in the selection of logistics center. Gamal (2018) integrated the Multi-Objective Optimization based on Ratio Analysis (MOORA) with neutrosophic set in order to find a solution for real supplier selection problems. The Neutrosophic MOORA method provides a solution procedure for how each alternative will be weighted according to the decreasing costs. Alava et al. (2018) offer a procedure which can find the solution of project selection. They combine Neutrosophic sets and AHP. Their procedure is composed of three steps, obtain information, weighting and rating alternatives, and selection of the project.

BWM is used to determine the weights of RPN's parameters. A two-step pairwise comparison is made in the BWM method. In the first stage, the best criterion is compared with other criteria. In the second stage, the worst criterion is compared with other criteria (Rezaei, 2015). BWM only uses integer values. In this respect, it is more practical than other methods (Rezaei et al. 2016). The BMW method has the following advantages such as (i) it provides highly consistent pairwise comparison and reliable results; (ii) pairwise comparison can be made using only two vectors. With this method, both less comparisons are made and more consistent results are obtained from the full matrix.

Gou and Zhao (2017) propose comparisons methodology for BWM. triangular fuzzy numbers are used in order to express decision-makers opinion. Then the graded mean integration representation methodology presented which calculate the weight of criteria and alternatives under fuzzy environment. Salimi and Rezaei (2016) applied BWM in order to incorporate the inputs and Outputs of Ph.D. Project and the industry's goal. They calculated a ratio which shows the efficiency of the project. Ahmadi et al. (2017), propose a model to examine the social sustainability of supply chains in manufacturing companies. They weighted social sustainability criteria using BMW. Mou et al. (2016) propose a methodology which integrates intuitionistic fuzzy sets with BWM for multi-criteria group decision making. Shojaei et al. (2018) evaluate airports services with integration BWM, VIKOR, and Taguchi

loss function. Nawaz et al. (2018) proposed a method that uses Markov chain and BWM methods together in cloud service selection. Architecture pattern was made with Markov chain and sequencing was done with BWM.

Although FMEA-based risk assessments studies are performed for evaluating project risks, as far as we know, FMEA based risk assessment has not been proposed for mechanical installation projects. Besides, BWM and NAHP methods have not been used as integrated yet. In this paper, a novel FMEA model based on BWN and NAHP is proposed for mechanical installation project. the contributions of this study can be summarized as follows: BWM used to prioritize the failure modes with respect to S, O, and D parameters. The BMW method is feasible and straightforward and offers very consistent results. Second, neutrosophic sets are used with AHP, which suggest an indeterminacy degree that helps experts to clarify their judgments more accurately and signifies the extent of decision makers disagreements.

2. METHODOLOGY

A quantitative FMEA based approach with BWM and NAHP integrated method. In the following section of the study, used method and how these methods are used together are explained. A flowchart of the proposed FMEA-based BWM and NAHP integrated approach is presented in Figure 1.

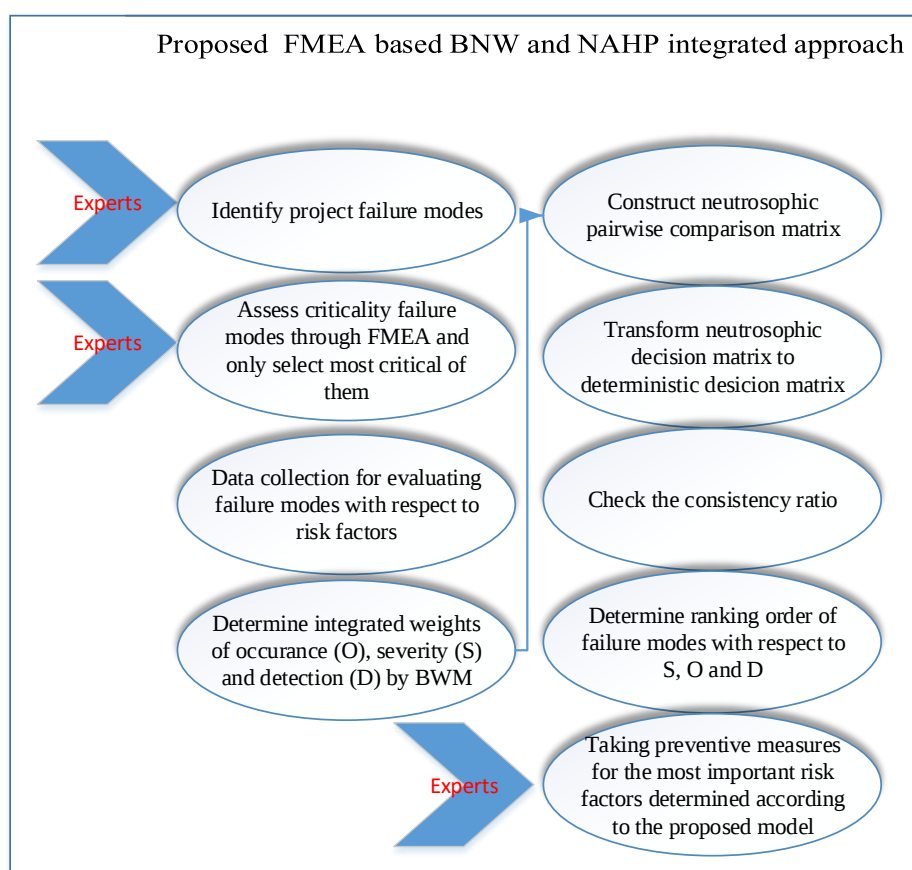


Figure 1:Flowchart of the proposed approach

2.1. Preliminaries

2.1.1. Preliminaries on Neutrosophic Sets

Neutrosophic sets is a general version of classical, fuzzy, and intuitionistic fuzzy sets (Abdel-Basset et al. 2017). They were first developed by Smarandache (2002). This set represents uncertainty better than other sets. (Abdel-Basset et al. 2018a). A single-valued triangular neutrosophic number is as follows: $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$. Where n_1, n_2, n_3 are the lower, median, and upper value of neutrosophic number and $\alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}}$ are the truth-membership, indeterminacy-membership and falsity-membership functions, respectively. These functions are defined as follows:

$$\begin{aligned} \text{The truth-membership function indicated as } T_{\tilde{n}}(x) &= \begin{cases} \alpha_{\tilde{n}} \left(\frac{x-n_1}{n_2-n_1} \right) & (n_1 \ll x \ll n_2) \\ \alpha_{\tilde{n}} & (x = n_2) \\ \alpha_{\tilde{n}} \left(\frac{n_3-x}{n_3-n_2} \right) & (n_2 \ll x \ll n_3) \\ 0 & \text{otherwise} \end{cases} \\ \text{The indeterminacy-membership function as } I_{\tilde{n}}(x) &= \begin{cases} \frac{(n_2-x+\beta_{\tilde{n}}(x-n_1))}{(n_2-n_1)} & (n_1 \ll x \ll n_2) \\ \beta_{\tilde{n}} & (x = n_2) \\ \frac{(x-n_2+\beta_{\tilde{n}}(n_3-x))}{(n_3-n_2)} & (n_2 \ll x \ll n_3) \\ 1 & \text{otherwise} \end{cases} \\ \text{The falsity-membership function as indicated } F_{\tilde{n}}(x) &= \begin{cases} \frac{(n_2-x+\theta_{\tilde{n}}(x-n_1))}{(n_2-n_1)} & (n_1 \ll x \ll n_2) \\ \theta_{\tilde{n}} & (x = n_2) \\ \frac{(x-n_2+\theta_{\tilde{n}}(n_3-x))}{(n_3-n_2)} & (n_2 \ll x \ll n_3) \\ 1 & \text{otherwise} \end{cases} \end{aligned}$$

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Here, $\alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}}$ demonstrate the maximum truth-membership degree, minimum indeterminacy-membership degree, and minimum falsity-membership degree, respectively. Some mathematical operations related to the neutrosophic sets are defined as in the following:

Definition 1 (Abdel-Basset et al. 2018a; 2018b): Addition of two triangular neutrosophic numbers.

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ and $\tilde{s} = \langle (s_1, s_2, s_3); \alpha_{\tilde{s}}, \beta_{\tilde{s}}, \theta_{\tilde{s}} \rangle$ be two single valued triangular neutrosophic numbers. Then addition of these two numbers can be computed as in Eq. (1):

$$\tilde{n} + \tilde{s} = \langle (n_1 + s_1, n_2 + s_2, n_3 + s_3); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle \quad (1)$$

Definition 2 (Abdel-Basset et al. 2018a; 2018b): Subtraction of two triangular neutrosophic numbers. This can be computed as in Eq. (2):

$$\tilde{n} - \tilde{s} = \langle (n_1 - s_3, n_2 - s_2, n_3 - s_1); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle \quad (2)$$

Definition 3 (Abdel-Basset et al. 2018a; 2018b): Inverse of a triangular neutrosophic number. Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ be a single valued triangular neutrosophic number. Then inverse of this number can be computed as in Eq. (3):

$$\tilde{n}^{-1} = \langle (\frac{1}{n_3}, \frac{1}{n_2}, \frac{1}{n_1}); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle \text{ where } \tilde{n} \neq 0 \quad (3)$$

Definition 4 (Abdel-Basset et al. 2018a; 2018b): Division of two triangular neutrosophic numbers

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ and $\tilde{s} = \langle (s_1, s_2, s_3); \alpha_{\tilde{s}}, \beta_{\tilde{s}}, \theta_{\tilde{s}} \rangle$ be two single valued triangular neutrosophic numbers. Then division of these two numbers can be computed as in Eq. (4):

$$\tilde{n}/\tilde{s} = \begin{cases} \langle (\frac{n_1}{s_3}, \frac{n_2}{s_2}, \frac{n_3}{s_1}); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & \text{if } n_3 > 0, s_3 > 0 \\ \langle (\frac{n_3}{s_3}, \frac{n_2}{s_2}, \frac{n_1}{s_1}); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & \text{if } n_3 < 0, s_3 > 0 \\ \langle (\frac{n_3}{s_1}, \frac{n_2}{s_2}, \frac{n_1}{s_3}); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & \text{if } n_3 < 0, s_3 < 0 \end{cases} \quad (4)$$

Definition 5 (Abdel-Basset et al. 2018a; 2018b): Multiplication of two triangular neutrosophic numbers

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ and $\tilde{s} = \langle (s_1, s_2, s_3); \alpha_{\tilde{s}}, \beta_{\tilde{s}}, \theta_{\tilde{s}} \rangle$ be two single valued triangular neutrosophic numbers. Then multiplication of these two numbers can be computed as in Eq. (5):

$$\tilde{n} * \tilde{s} = \begin{cases} \langle (n_1 * s_1, n_2 * s_2, n_3 * s_3); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & \text{if } n_3 > 0, s_3 > 0 \\ \langle (n_1 * s_3, n_2 * s_2, n_3 * s_1); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & \text{if } n_3 < 0, s_3 > 0 \\ \langle (n_3 * s_3, n_2 * s_2, n_1 * s_1); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & \text{if } n_3 < 0, s_3 < 0 \end{cases} \quad (5)$$

2.2. FMEA

FMEA, which proposes a process in risk management decisions, was first used in the 1960s space industry. Although this method was first used in the space industry, it was used as a risk assessment tool in many different sectors in the following years (Chang et al. 2013; Akyuz and Celik, 2018). The specified parameters can be called failure modes when used in an error analysis (Liu et al. 2015). FMEA is a risk assessment procedure used to identifying prioritizing and eliminating, failure modes in systems, designs, projects before the actual consequences of the failure occur (Stamatis, 2003). Traditional FMEA technique uses of RPN offered in order to determine risk priorities of failure modes. The RPN contains risk factors, such as the occurrence of a failure mode (O), the severity of a failure effect (S) and the probability of not detecting the failure (D), should evaluate effectively Then RPN is calculated by multiplying of the risk factors. The failure mode with a high RPN value is more important than the others (Liu et al. 2015; Jiang et al. 2017 Zhou and Thai, 2016; Fattahi and Khalilzadeh, 2018). In the literature, the traditional RPN has been criticized for many reasons, such as not being able to fully determine the importance of risks (Wang et al. 2009). Different composition of O, S, and D scores with different risk factors can produce the same RPN values. In this case, the risk factors cannot be evaluated according to the areas used. Although the RPN is the same, the risk weights may be completely different. Conventional FMEA; does not consider the relative weights of O, S, and D. This contradicts real-life

practices (Zhao, 2017). In this study, S, O, and D parameters are weighted by the BMW method to overcome this weakness.

Unlike other risk assessment procedures, FMEA aims to continuously improve the system rather than identifying corrective actions after an error occurs. Thus, decision-makers can improve existing proses, and prepare preventive measures to minimize the possibility of failure. FMEA has already become widespread in industries such as automotive, health, nuclear, military, and space (Song et al. 2014, Liu et al. 2014; Su et al. 2012).

2.3. Steps of NAHP

The solution of NAHP and classic AHP is very similar. The most significant difference that distinguishes NAHP from AHP is the use of neutrosophic scale (see Table 1) instead of the traditional Saaty (1990) (1-9) scale.

Table 1: Linguistic terms and corresponding triangular neutrosophic numbers

Saaty scale	Corresponding linguistic term	Neutrosophic triangular scale	Reciprocal neutrosophic triangular scale
1	Equally Influential (EI)	{(1, 1, 1);0.5, 0.5, 0.5}	{(1, 1, 1);0.5, 0.5, 0.5}
2	Sporadic values between EI and SI	{(1, 2, 3);0.4, 0.65, 0.6}	{(0.33, 0.5, 1);0.4, 0.65, 0.6}
3	Slightly Influential (SI)	{(2, 3, 4);0.3, 0.75, 0.7}	{(0.25, 0.33, 0.5);0.3, 0.75, 0.7}
4	Sporadic values between SI and STI	{(3, 4, 5);0.6, 0.35, 0.4}	{(0.2, 0.25, 0.33);0.6, 0.35, 0.4}
5	Strongly Influential (STI)	{(4, 5, 6);0.8, 0.15, 0.2}	{(0.17, 0.2, 0.25);0.8, 0.15, 0.2}
6	Sporadic values between STI and VSI	{(5, 6, 7);0.7, 0.25, 0.3}	{(0.14, 0.17, 0.2);0.7, 0.25, 0.3}
7	Very Strongly Influential (VSI)	{(6, 7, 8);0.9, 0.1, 0.1}	{(0.13, 0.14, 0.17);0.9, 0.1, 0.1}
8	Sporadic values between VSI and AI	{(7, 8, 9);0.85, 0.1, 0.15}	{(0.11, 0.13, 0.14);0.85, 0.1, 0.15}
9	Absolutely Influential (AI)	{(9, 9, 9);1, 0, 0}	{(0.11, 0.11, 0.11);1, 0, 0}

The step-by-step solution procedure for NAHP is listed as follows (Abdel-Basset et al., 2017).

Step 1. In this step, the hierarchical structure of the problem is determined.

Step 2. After establishing the hierarchical structure of the problem in the first step, neutrosophic judgment matrix is formed. When creating the decision matrix, Table 1 is used.

The linguistic assessments of decision makers are triangular neutrosophic numbers $\tilde{a}_{ij}$. Then construct the neutrosophic pair-wise comparison such that.

$$\tilde{A} = \begin{bmatrix} \tilde{1} & \tilde{a}_{12} & \tilde{a}_{1n} \\ \tilde{M} & \tilde{O} & \tilde{M} \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{1} \end{bmatrix}$$

Where $\tilde{a}_{ji} = \tilde{a}_{ij}^{-1}$

Step 3 To prioritize alternatives and determine the order of all alternatives, First of all, the comparison matrix must be created.

Step 4. In order to calculate the weight of each criterion from the corresponding neutrosophic pair-wise comparison matrix, neutrosophic pair-wise comparison matrix is transformed to deterministic pair-wise comparison matrix, using Eq (6-7):

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \theta_{\tilde{n}}, \beta_{\tilde{n}} \rangle$ be a single-valued triangular neutrosophic number, then,

$$S(\tilde{n}_{ij}) = \frac{1}{8} [n_1 + n_2 + n_3] x (2 + \alpha_{\tilde{n}} - \beta_{\tilde{n}} - \theta_{\tilde{n}}) \quad (6)$$

$$A(\tilde{n}_{ij}) = \frac{1}{8} [n_1 + n_2 + n_3] x (2 + \alpha_{\tilde{n}} - \beta_{\tilde{n}} - \theta_{\tilde{n}}) \quad (7)$$

Once the necessary conversion is made, the decision matrix is created as follows.

$$A = \begin{bmatrix} 1 & a_{12} & a_{1n} \\ M & O & M \\ a_{n1} & a_{n2} & L & 1 \end{bmatrix}$$

Step 5. To measure an inconsistency within the judgments in each comparison matrix and for the entire hierarchy, AHP methodology provides a consistency index (CI) (Kadoić et al. 2017) to discerns if there is any inconsistency in neutrosophic judgment matrix, AHP utilizes consistency index and consistency ratio (CR). If CR is greater than 0.1, the decision-makers made random evaluations. Evaluations are untrustworthy; also they must be repeated.

To calculate D, E, λ CI, and CR do the following steps:

$$D = \begin{bmatrix} 1 & a_{12} & a_{1n} \\ M & O & M \\ a_{n1} & a_{n2} & L & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ M \\ w_n \end{bmatrix} \quad (8)$$

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All the elements of the (nx1) dimensional D column vector found are divided into weight column matrix elements corresponding to the element, respectively, with using Eq (9). Thus, the value of E, which is the primary value for each evaluation factor, is determined. The arithmetic means of the E values calculated with Eq (10) and obtained the eigenvector value called λ .

$$E = \frac{d_i}{w_i} \quad (9)$$

$$\lambda = \frac{\sum_{i=1}^n E_i}{n} \quad (10)$$

Once the eigenvector is identified, the Consistency Index (CI) is calculated by the following formula Eq (11)

$$CI = \frac{\lambda - n}{n - 1} \quad (11)$$

The Consistency Ratio (CR) value should be divided by the value of the resulting CI to the value of RI (Random Index) Eq (12) as shown in the equation below (Gul et al., 2017). This is the consistency index of the comparison matrix.

$$CR = \frac{CI}{RI} \quad (12)$$

The last step in the calculation of NAHP. It is the stage of calculating the overall priority of each alternative and determining the sequence of all alternatives.

2.4. Steps of BNW

BWM is introduced by Rezaei (2015). The application steps are listed below.

Step 1. At this stage, we aim to determine the weights of O, S and D parameters used in the calculation of RPN.

Step 2. At this stage; The best and worst parameter between S, O, D is determined. There is no comparison in this step.

Step 3. Using the numbers 1 to 9, it is determined how different the other criteria from the best criterion. The resulting Best-to-Others vector would be: $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$, Where a_{Bj} indicates the preference of the best criterion B over criterion j . It is clear that $a_{BB} = 1$

Step 4. Using the numbers 1 to 9, it is determined how different the other criteria from the worst criterion. The resulting Others-to-Worst vector would be

$A_B = (a_{1W}, a_{2W}, \dots, a_{nW})^T$ where a_{jW} indicates the preference of the criterion j over the worst criterion W . It is clear that $a_{WW} = 1$.

Step 5. Find the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$.

The optimal weight for the criteria is the one where for each pair of w_B/w_j and w_j/w_W we have $w_B/w_j = a_{jW}$. To satisfy these for all j , we should find a solution where the maximum absolute differences $\left| \frac{w_B}{w_j} - a_{Bj} \right|$ and $\left| \frac{w_j}{w_W} - a_{jW} \right|$ for all j is minimized. Considering the non-negativity and sum condition for the weights, the following problem has resulted:

$$\min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\}$$

s.t

$$\sum w_j = 1$$

$$w_j \geq 0 \text{ for all } j$$

The problem has been transformed as follows.: ξ

$\min \xi$

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi \text{ for all } j$$

$$\left| \frac{w_j}{w_W} - a_{jW} \right| \leq \xi \text{ for all } j$$

$$\sum w_j = 1$$

$$w_j \geq 0, \text{ for all } j$$

Solving problem, the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$, and ξ^* are calculated. Consistency index is calculated using Table 2.. ξ^* value will increase the consistency ratio to be high. The higher the consistency rate, result in the more unreliable evaluation.

Table 2: Consistency Index

a_{BW}	1	2	3	4	5	6	7	8	9
consistency index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

2.5. Steps of Novel FMEA-Based BWM and NAHP

BWM and NAHP methods are used as integrated to implement a FMEA-based risk assessment approach in mechanical installation projects. The weights of FMEA parameter S, O and D are calculated by BWM. Then, obtain ranking orders of failure modes with respect to S, O and D by NAHP.

Stage 1. In this study, Nine failure mode in mechanical installation projects is evaluated respect to three FMEA parameters. FMEA team is set up in the field where the application is made by selecting 5 experts. Descriptions and potential results of the failure modes are given in Table 3, information for the evaluator experts are presented in Table 4.

Table 3: The Encountered Failure Modes in the Mechanical Installation Project

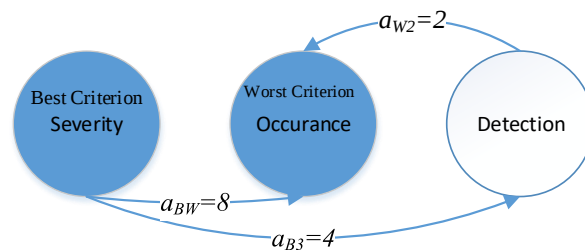
Failure mode	Description of failure mode	Potential results of failure mode
FM1	Safety valve not installed in the heating boiler.	If the system pressure is above or below the boiler operating pressure, there is a risk of explosion of the boiler due to the lack of a safety valve for the evacuation
FM2	No replacement pump installed in the heating system	If there is no backup pump in the system in case of failure of the main pump, the system will not start and stop.
FM3	No expansion joints in building	The process of settling the new constructions on the ground can be several years, and stretching can be experienced in this process, which may cause vibrations and thermal expansion in the pipelines. The absence of the compensator causes the pipes to be torsion and exposed to vibrations, causing cracks in the pipelines.
FM4	No automatic discharge line to the end point of the installation	There are constant problems in the operation of the system from the air flow.
FM5	Failure to clean the dirt caught in the suction line	If the dirt trap is not clean, the dirty water in the circulation pump will cause malfunctions and damage the system.
FM6	Do not install the manometer that must be installed on the heating line	The water and pressure in the main lines cannot be determined. Water testing cannot be carried out and instant control cannot be performed.
FM7	Failure to install the thermometer in the mainline heating system	The temperature of the water in the system cannot be determined. The loss in the temperature of the water coming to the return collector cannot be measured.
FM8	Lack of rubber compensator in circulation pump.	Circulation pump produces sound and vibration. The operating efficiency of the system is reduced.
FM9	Lack of pressure reducer in the boiler	The 10 bar pressure from the main line decreases the life of the boiler by going directly to the boil without decreasing to 5-6 bar.

Table 4: Information for the Evaluator Expert Team

Expert ID	Title	Year of experience
Expert-1	Senior Mechanical Engineer	20
Expert-2	Mechanical Engineer	10
Expert-3	Mechanical Engineer	5
Expert-4	Senior Mechanical technician	10
Expert-5	Mechanical Technician	3

Stage 2. This section covers the determination of FMEA risk parameters weights with BWM. The steps of BWM is expressed in section 2.4. Due to the space limitations, only the calculation of the evaluation of Expert1 is presented here.

Expert 1, assigns 8 to show the importance of S over O, this comparison represents as a_{BW} . It is the reference comparison. The second comparison is S over D ($a_{B3} = 4$). All comparisons are representing in Figure 3.

**Figure 3: BWM Comparison Chart**

The mathematical formulation of BMW of Expert 1 is as follows:

$\min \xi$

st.

$$\left| \frac{w_1}{w_3} - 4 \right| \leq \xi, \quad \left| \frac{w_1}{w_2} - 8 \right| \leq \xi, \quad \left| \frac{w_3}{w_2} - 2 \right| \leq \xi,$$

$$w_1 + w_2 + w_3 = 1$$

$$w_1, w_2, w_3 \geq 0$$

where w_1 represents S, w_2 O and w_3 are D. Results are found as 0.727, 0.091 and 0.182, respectively also ξ is found 0 which used in CR calculation. Then we calculated the CR, using ξ and the CI by Eq(12) (see Table 2) , as follows:

$$\text{Consistency Ratio} = \frac{\xi}{\text{Consistency Index}}$$

(13)

CR calculated $0/4.47=0$, which implies a full consistency. All the evaluations of failure modes and CR are provided in Table 5.

Table 5: Evaluations of Failure Modes and CR

	Expert1	Expert2	Expert3	Expert4	Expert 5	Aggregate
W1(S)	0.727	0.697	0.727	0.684	0.671	0.7012
W2(O)	0.091	0.077	0.182	0.216	0.072	0.1276
W3(D)	0.182	0.231	0.091	0.100	0.257	0.1721
CR	0	0	0	0.043	0.075	

Stage 3: The steps of NAHP is expressed in section 2.3. Neutrosophic pair-wise comparison matrix for the failure modes with respect to each of three risk parameters in FMEA is provided. The neutrosophic decision matrixes are transformed into deterministic decision matrix using the Eq. (6-7). Due to the space limitations, the transformed and aggregated deterministic pair-wise comparison matrices are only presented as Tables 6-8.

Table 6: Pair-wise Comparison Matrix of Failure Modes According to Severity Parameter

Severity	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9
FM2	0.12	0.56	0.13	2.39	0.68	0.18	0.19	0.88	0.56
FM3	0.79	7.52	0.56	8.12	5.43	1.61	1.99	5.88	6.33
FM4	0.12	0.42	0.12	0.56	0.12	0.18	0.24	0.76	0.15
FM5	0.12	1.47	0.18	8.69	0.56	0.22	0.25	1.65	0.56
FM6	0.78	5.42	0.62	5.47	4.47	0.56	0.41	5.33	1.59
FM7	1.09	5.38	0.50	4.15	4.06	2.42	0.56	5.64	2.41
FM8	0.12	1.13	0.17	1.31	0.61	0.19	0.18	0.56	0.18
FM9	0.18	1.78	0.16	6.69	1.78	0.63	0.41	5.66	0.56
Total of the row	3.87	31.98	3.72	45.98	26.28	7.28	5.15	34.94	18.03

Table 7: Pair-wise Comparison Matrix of Failure Modes According to Occurrence Parameter

Occurrence	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9
FM1	0.56	3.55	0.50	0.17	0.16	0.34	0.41	0.13	0.18
FM2	0.28	0.56	6.92	0.18	0.19	0.86	0.84	0.14	0.34
FM3	1.99	0.14	0.56	0.13	0.13	0.23	0.16	0.13	0.19
FM4	5.94	5.70	7.78	0.56	0.50	3.92	3.14	0.17	2.78
FM5	6.32	5.33	7.52	1.99	0.56	4.78	4.33	0.50	6.87
FM6	2.97	1.16	4.27	0.26	0.21	0.56	0.35	0.23	0.50
FM7	2.42	1.19	6.40	0.32	0.23	2.87	0.56	0.22	0.35
FM8	7.78	7.39	7.78	5.85	1.99	4.31	4.60	0.56	4.28
FM9	5.70	2.95	5.33	0.36	0.15	1.99	2.88	0.23	0.56
Total of the row	33.96	27.99	47.06	9.80	4.12	19.85	17.27	2.31	16.04

Table 8: Pair-wise Comparison Matrix of Failure Modes According to the Detection Parameter

Detection	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9
FM1	0.56	8.59	0.62	8.12	7.53	3.55	3.19	8.00	5.69
FM2	0.12	0.56	0.14	0.19	0.28	0.19	0.18	0.17	0.64
FM3	1.61	7.37	0.56	8.00	8.00	6.94	3.71	7.39	5.03
FM4	0.12	5.38	0.13	0.56	0.68	0.17	0.16	0.62	1.67
FM5	0.13	3.63	0.13	1.46	0.56	0.16	0.16	0.64	0.72
FM6	0.28	5.25	0.14	5.90	6.40	0.56	0.56	2.76	0.84
FM7	0.31	5.64	0.27	6.23	6.26	1.78	0.56	4.33	2.01
FM8	0.13	5.94	0.14	1.61	1.56	0.36	0.23	0.56	5.83
FM9	0.18	1.56	0.20	0.60	1.39	1.19	0.50	0.17	0.56
Total of the row	3.44	43.93	2.32	32.66	32.66	14.90	9.25	24.63	22.99

The normalized matrix and priority vectors of failure modes based on three risk parameters are computed respectively as in Tables 9-11. In doing this, Eq (8) is used. Also, the eigenvector is computed using Eq (9).

Table 9: Normalized Matrix and Priority Vector of Failure Modes Based on Severity Parameter

Severity	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	Priority vector
FM1	0.145	0.260	0.340	0.187	0.327	0.176	0.178	0.246	0.316	0.242
FM2	0.031	0.018	0.036	0.052	0.026	0.025	0.036	0.025	0.031	0.031
FM3	0.205	0.235	0.151	0.177	0.207	0.221	0.387	0.168	0.351	0.233
FM4	0.030	0.013	0.033	0.012	0.004	0.025	0.047	0.022	0.008	0.022
FM5	0.030	0.046	0.050	0.189	0.021	0.031	0.048	0.047	0.031	0.055
FM6	0.202	0.170	0.167	0.119	0.170	0.077	0.080	0.152	0.088	0.136
FM7	0.281	0.168	0.135	0.090	0.154	0.332	0.109	0.161	0.134	0.174
FM8	0.030	0.035	0.046	0.029	0.023	0.026	0.034	0.016	0.010	0.028
FM9	0.045	0.056	0.042	0.145	0.068	0.087	0.081	0.162	0.031	0.080

Table 10: Normalized Matrix and Priority Vector of Failure Modes Based on Occurrence Parameter

Occurrence	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	Priority vector
FM1	0.017	0.127	0.011	0.017	0.038	0.017	0.024	0.056	0.011	0.035
FM2	0.008	0.020	0.147	0.018	0.046	0.043	0.049	0.059	0.021	0.046
FM3	0.059	0.005	0.012	0.013	0.032	0.012	0.009	0.056	0.012	0.023
FM4	0.175	0.204	0.165	0.057	0.122	0.197	0.182	0.074	0.173	0.150
FM5	0.186	0.190	0.160	0.203	0.137	0.241	0.251	0.218	0.428	0.224
FM6	0.087	0.042	0.091	0.026	0.051	0.028	0.020	0.100	0.031	0.053
FM7	0.071	0.043	0.136	0.032	0.056	0.145	0.033	0.094	0.022	0.070
FM8	0.229	0.264	0.165	0.596	0.483	0.217	0.267	0.243	0.267	0.303
FM9	0.168	0.106	0.113	0.037	0.035	0.100	0.167	0.101	0.035	0.096

Table 11: Normalized matrix and Priority Vector of Failure Modes Based on Detection Parameter

Detection	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	Priority vector
FM1	0.164	0.196	0.269	0.249	0.231	0.238	0.345	0.325	0.247	0.251
FM2	0.034	0.013	0.059	0.006	0.008	0.013	0.019	0.007	0.028	0.021
FM3	0.467	0.168	0.243	0.245	0.245	0.466	0.401	0.300	0.219	0.306
FM4	0.036	0.122	0.054	0.017	0.021	0.011	0.017	0.025	0.072	0.042
FM5	0.039	0.083	0.054	0.045	0.017	0.010	0.017	0.026	0.031	0.036
FM6	0.082	0.120	0.062	0.181	0.196	0.038	0.061	0.112	0.037	0.099
FM7	0.091	0.128	0.116	0.191	0.192	0.119	0.061	0.176	0.087	0.129
FM8	0.036	0.135	0.058	0.049	0.048	0.024	0.025	0.023	0.254	0.073
FM9	0.051	0.035	0.086	0.018	0.043	0.080	0.054	0.007	0.024	0.044

The CR values of the three matrices are calculated as step 5 in section 2.3. the consistency of experts' evaluations. According to the results of the calculations made in Table 12, experts' judgments in all three matrices are found consistent (equal to or lower than 0.1). The RI value for n=9 is set to 1.45, according to the study of Alonso et al. (2006).

Table 12: Results of Consistency Test for S, O, D

	S	O	D
$\lambda_{\max}$	0.7012	0.1276	0.1721
CI	0.040	0.139	0.125
RI	1.45	1.45	1.45
CR	0.027	0.096	0.085

Finally, priority scores of each failure mode are computed as by multiplying the weight vector of risk parameters and the priority vector of failure modes with respect to three risk parameters priority vector obtained in Tables 9-12, follows:

$$\begin{bmatrix} 0.242 & 0.035 & 0.251 \\ 0.031 & 0.046 & 0.021 \\ 0.233 & 0.023 & 0.306 \\ 0.022 & 0.150 & 0.042 \\ 0.055 & 0.224 & 0.036 \\ 0.136 & 0.053 & 0.099 \\ 0.174 & 0.070 & 0.129 \\ 0.028 & 0.303 & 0.073 \\ 0.080 & 0.096 & 0.044 \end{bmatrix} \times \begin{bmatrix} 0.701 \\ 0.128 \\ 0.172 \end{bmatrix} = \begin{bmatrix} 0.217 \\ 0.031 \\ 0.219 \\ 0.042 \\ 0.073 \\ 0.119 \\ 0.153 \\ 0.071 \\ 0.076 \end{bmatrix}$$

In Figure 4, final priority scores of failure modes are provided. According to these results, FM3 is the most important failure mode that observed the mechanical installation project. It is followed by FM1, FM7, and FM6, respectively. The final score of failure modes represented Figure 4.

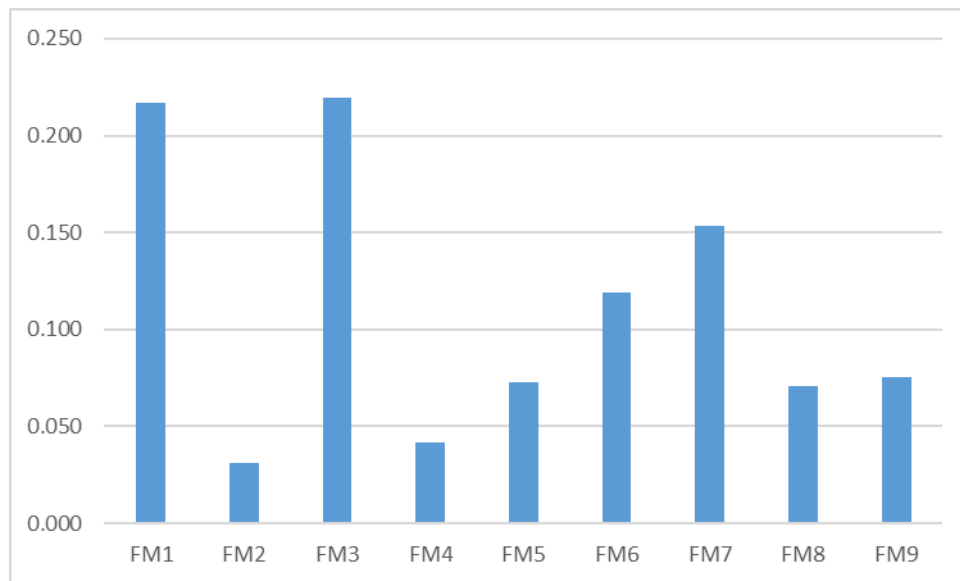


Figure 4: Final Scores of Failure Modes Respect to FMEA Risk Assessment

3. CORRECTIVE-PREVENTIVE ACTIONS PLANNING FOR MECHANICAL INSTALLATION PROJECT

According to the results of FMEA-based BWM-NAHP integrated approach, preventive measures were proposed for the 4 most critical failure modes. These suggestions can be listed as follows.

FM3: In order to prevent damage to the piping system due to the ground motion, the equipment must be fitted during the installation of the pipes and the components which will be obliged to connect to the compensator. During the combination of the pipes at the crossing points on the foundations, the technical team should be in charge, and the necessary procedures should be taken into consideration.

FM1: Additional sensors may be provided for the discharge of pressure in the return line and the interior of the expansion tank. The threaded joint where the safety valve is to be installed can be marked before installation. Besides, an electronic sensor can be used to prevent the system from operating without the safety valve being installed.

FM6: It can be added to the procedures to start the tests after checking that the manometer is fitted to the mainline system.

FM7: It can be added to the procedures to start the tests after checking that the thermometer is fitted to the mainline system.

4. CONCLUSION

FMEA is a risk assessment procedure used to identifying prioritizing and eliminating, failure modes in systems, designs, projects before the actual consequences of the failure occur. The RPN is the fundamental assessment criteria for FMEA-based risk assessment practices. Traditionally, O, S, and D risk factors multiplication to calculate RPN, which need to be accurately evaluated. However, the traditional RPN calculation method has been heavily criticized for many reasons, such as not considering the weight of the risk factors. To overcome this disadvantage, a FMEA based risk assessment model has been proposed for mechanical installation projects. The weight of FMEA parameters S, O and D are calculated

using the BMW method, which gives very consistent results. To evaluate failure models, according to S, O and D parameters, NAHP method is used. AHP integrated with neutrosophic sets because Neutrosophic sets provide real-world issues by considering truthiness, indeterminacy and falsity aspects of decision-making.

This study will bring innovation to the literature in some respects as follows and will give a general idea for the creation of new studies.

(I) Although FMEA-based risk assessment procedures are widely used in other areas such as designs, products, processes, FMEA-based assessment of project risks is quite rare.

(II) The NAHP method is used for the first time for a FMEA-based project risk assessment procedure. This integration represented ambiguities better.

(III) As far as we know, FMEA based project risk assessment with BWM-NAHP integration has not been applied before.

As a result of the calculations, the highest risk factor was determined as FM3. FM3 was followed by FM1, FM7 and FM6. FM3 has been identified as the most important risk factor because even if this risk is detected, it causes irreversible damage to the structure. In this respect, attention should be paid to this risk in projects to be carried out and it should be checked whether necessary measures have been taken. FM2 was the least significant risk factor. FM2 can be easily detected and necessary preventive measures can be taken easily.

In future studies, the authors intend to use this proposed methodology in other areas that require FMEA-based risk assessment. Also, the proposed methodology's BMW section should be extended with fuzzy or neutrosophic sets.

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