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Fine-Kinney-Based Occupational Risk Assessment using Pythagorean Fuzzy AHP-COPRAS for the Lifting Equipment in the Energy Distribution and Investment Sector

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Highlights

- A Pythagorean fuzzy based risk model is developed for Energy Distribution and Investment Sector.
- The Fine-Kinney-based PFAHP and PFCOPRAS integrated approach was proposed.
- Hazards from lifting equipment are ranked using PFCOPRAS.
- A sensitivity analysis was performed for validation of results.

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Abstract

The initial risk assessment, especially when using a risk score system, is the main step in a risk assessment process that comes after determining the scope of the risks and assessment. Risk assessment frequently employs the Fine-Kinney method, a comprehensive strategy for quantitative assessments that helps keep risks under check. A risk score (RS) is defined using the standard version of Fine-Kinney by mathematically multiplication of probability (P), exposure (E), and consequence (C) parameters. The Fine-Kinney-based risk evaluation approach has the disadvantage of not accounting for the relationships among the risk parameters' interaction and determining the risk precedence of work-related hazards. Hence, to decrease the negative effects of increasing risks, a new hazard evaluation system for occupational health and safety (OHS) is necessary. In this paper, a novel approach is proposed for integrating Fine–Kinney-based occupational hazard evaluation and AHP-COPRAS for the energy distribution and investment sector under the Pythagorean fuzzy environment. Lifting equipment in energy distribution and investment sector case study is used to demonstrate the practicality and efficacy of the suggested integrated approach. To verify the novel method to risk assessment, a comparative study and sensitivity analysis are also provided. As a result, using the benefit of Pythagorean fuzzy sets, which more effectively express uncertainty, the integrated approach yields more logical conclusions for assessing work-related hazards in the energy distribution and investment sector.

1. INTRODUCTION

Electricity has indispensable importance in human life. Electricity is a sector where the danger is high as well as important for human life. There are a lot of fatal occupational accidents in the electricity industry according to the Ceylan [1] study. Electricity distribution companies are responsible for the transmission and distribution of electrical energy to all places where consumption is made. Due to its structure, people working in this sector are likely to encounter the risk of electrical accidents. Aslan and Çelik [2] found in their study that a significant part of the workers working in the electricity distribution sector had a work accident. Risk assessment, identifying existing and external workplace hazards by experts, prioritizing risks by analyzing, and eliminating risks at their source; if this is not possible, it includes the processes of reducing it to the level specified as the acceptable risk level and controlling it at regular intervals [3]. It is of great importance to carry out a risk assessment by using effective methods to prevent the risks arising from the hazards in the works done in the electricity sector, where the vital risk is so important.

A logical approach to evaluating risks' qualitative and quantitative values as well as their possible effects on people, things, equipment, materials, and the environment is known as risk assessment [4,5]. While risk

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analysis involves using actual data in a methodical manner to establish hazards, risk evaluation involves making decisions about how tolerable a risk is based on several factors. When hazards are assessed using standard methods to provide a precise rating, decision-makers frequently confront difficulties. To address these issues, integrated approaches in a fuzzy environment have been created [6,7]. Therefore, Pythagorean fuzzy sets, a more recent application of fuzzy set theory, and a hybrid AHP-COPRAS approach are used in this study. Pythagorean fuzzy set is an extension of intuitionistic fuzzy sets. It gives specialists additional leeway to convey their views on the ambiguity and unpredictability of the problem under consideration in risk assessment. Experts award membership and non-membership degrees in Pythagorean fuzzy sets [8]. In the Pythagorean fuzzy sets, the assigned membership and non-membership degrees do not have to add up to 1, unlike intuitionistic fuzzy sets. The summation of the squares of membership and non-membership degrees must, however, not exceed 1 [9]. On the other hand, Multi-Criteria Decision-Making (MCDM) is a strategy used for solving complicated problems by examining many alternatives while taking into account several criteria and competing goals. These techniques give decision-makers and policy creators the ability to use a technical methodology that makes use of technical information to get a more reasoned and scientifically sound choice [10]. The results from each method could be the different or same. In this manner, MCDM techniques assist in resolving a choice problem that frequently calls for taking several viewpoints into account [11].

In this paper, an integrated approach to the Fine-Kinney-based Pythagorean Fuzzy Analytic Hierarchy Process (PFAHP) and Pythagorean fuzzy Complex Proportional Assessment (PFCOPRAS) is suggested for the evaluation of risks in lifting equipment used in the energy distribution and investment sector. 25 risks have been identified in this field, in the opinions of experts. The results of this study will provide guidance to stakeholders who use lifting tools to assess hazards and risks. For this reason, by using the benefit of Pythagorean fuzzy sets, which offer more effective solutions in uncertain situations with the proposed approach, it may provide more reasonable results in assessing the risks associated with lifting equipment used in the energy distribution and investment industry. The major contributions of the paper include the following: (1) for the first time, the Fine-Kinney-based PFAHP and PFCOPRAS integrated approach was proposed in occupational hazard evaluation, (2) The proposed integrated approach has been applied for the first time to the risk assessment of lifting equipment in the energy distribution and investment sector, (3) the outcomes of classical Fine-Kinney method, Fine-Kinney-based AHP-COPRAS method and integrated PFAHP and PFCOPRAS approach were analyzed and compared in the case study, (4) a sensitivity analysis was conducted to confirm the outcomes.

The rest of the paper is structured as follows: the second part includes a literature search of the applied methodologies. The applied methods, Fine-Kinney-based occupational hazard evaluation and PFAHP and PFCOPRAS are presented in the third part, where the procedure for each method is provided stepwise. The case of lifting equipment activities is tested to weigh the risk parameter and rank the hazards in the fourth part. Lastly, the final part provides concluding comments on future research.

2. LITERATURE REVIEW

This section examines methods for assessing occupational health and safety risk while taking into account recently released findings and concentrating on Pythagorean fuzzy AHP and COPRAS based methods. Since Pythagorean fuzzy sets were initially developed, numerous studies have been carried out on MCDM issues using Pythagorean fuzzy sets [12-19]. Moreover, Peng and Selvachandran [20] discussed COPRAS-based Pythagorean fuzzy integrated techniques. To provide a clear point of view about various concepts, methods, and developments connected to their expansion, they give an outline of the Pythagorean fuzzy set.

In the proposed integrated method, after the Fine-Kinney-based risks criterion weights are defined by PFAHP in the first stage, the 25 hazards of lifting equipment in the energy and investment sector are sorted using the PFCOPRAS method in the second stage. Because the COPRAS method is simple to apply to situations involving complicated criteria and offers a variety of options for MCDM methods, the method is utilized to a wide range of topics in the literature. The COPRAS utilized various study fields in the literature including risk assessment [21,22]; Selection of investment projects [23]; Digital supply chain partner selection [24]; COVID-19 regional safety assessment [25]; Green supplier selection [26]; selecting desalination technology [27]; Sustainability assessment of bioenergy production [28]. Moreover, Ilbahar et al. [29] suggested an approach that integrates the Fine-Kinney method with the Pythagorean Fuzzy AHP for the calculation of risk factors. Gul et al. [9] proposed integrating Fine-Kinney-based interval-valued Pythagorean fuzzy VIKOR methods. A case study was conducted in the chrome plating unit of a gun manufacture to demonstrate that the approach they have proposed is applicable. Rani et al. [30] conducted an integrated Pythagorean fuzzy set-based Entropy-COPRAS to solve the problem of pharmacological treatment selection for T2D patients. Büyüközkan and Göçer [24] presented a Pythagorean cluster based AHP and COPRAS hybrid study and used it in the example of digital supply chain partner selection in their study.

In the proposed study, unlike previous studies, for the first time in the literature the Fine-Kinney-based occupational risk assessment and PFAHP and PFCOPRAS hybrid method, and a case study is made for the lifting equipment used in the energy distribution and investment sector.

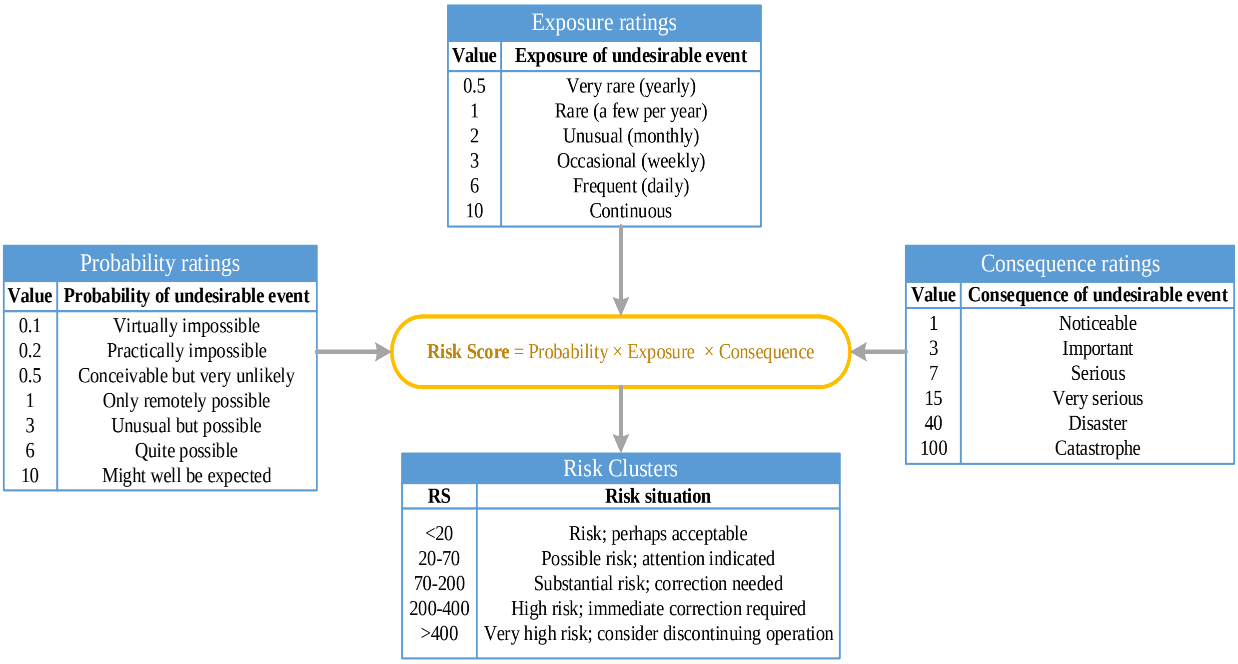
3. METHODOLOGY

In this part, the methodology of this paper, namely Fine-Kinney-based occupational hazard evaluation and PFAHP and PFCOPRAS methods is discussed. The suggested approaches not only eliminate the ambiguity and unpredictability of the actual environment, and improve decision-makers' expression, but also significantly lessen the complexity of calculation.

3.1. Fine-Kinney Method

One of the quantitative risk analysis techniques is the Fine-Kinney method. This method was devised by Kinney and Wiruth [31]. It is a frequently used hazard evaluation method today [32]. The values of probability, exposure, and consequence are multiplied in the Fine-Kinney hazard evaluation approach ($\mathrm{RS} = \mathrm{P} \times \mathrm{E} \times \mathrm{C}$). As a result of the multiplication, a risk score is obtained. In this paper, Fine-Kinney risk parameters (probability, exposure, and consequence) were considered during ranking hazards in lifting equipment in the energy distribution and investment sector. The classical Fine-Kinney method was applied to the case study and the outcomes were compared with the integrated proposed method. The weights of the three risk parameters were calculated using the following the interval valued PFAHP approach. These terms are explained below.

Probability refers to the probability of loss or damage over time. Exposure refers to the frequency of hazard event. Consequence refers to the degree of impact that a hazardous situation will have when it occurs. These three provided parameters are multiplied to provide the Risk Score. In Figure 1, the ratings for these three parameters are displayed.



Exposure ratings

Value	Exposure of undesirable event
0.5	Very rare (yearly)
1	Rare (a few per year)
2	Unusual (monthly)
3	Occasional (weekly)
6	Frequent (daily)
10	Continuous

Probability ratings

Value	Probability of undesirable event
0.1	Virtually impossible
0.2	Practically impossible
0.5	Conceivable but very unlikely
1	Only remotely possible
3	Unusual but possible
6	Quite possible
10	Might well be expected

Risk Score = Probability × Exposure × Consequence

Consequence ratings

Value	Consequence of undesirable event
1	Noticeable
3	Important
7	Serious
15	Very serious
40	Disaster
100	Catastrophe

Risk Clusters

RS	Risk situation
<20	Risk; perhaps acceptable
20-70	Possible risk; attention indicated
70-200	Substantial risk; correction needed
200-400	High risk; immediate correction required
>400	Very high risk; consider discontinuing operation

***Figure 1.** Fine-Kinney method flowchart*

3.2. Pythagorean Fuzzy Set

In this subsection, certain preliminary Pythagorean fuzzy sets and accompanying notations are explained before providing steps of the suggested integrated technique. People make decisions in their daily life. As most of these decisions they make are complex and fuzzy, it is sometimes insufficient to express them numerically (crisp set). When crisp sets are insufficient, the fuzzy set theory has been the answer [33]. The fact that the total of the degrees of membership and non-membership cannot exceed 1 in an intuitive fuzzy set may not always be sufficient to identify uncertainty. When intuitive sets are insufficient, Yager [8] generalized form of Pythagorean fuzzy sets is used. In Pythagorean fuzzy sets, unlike intuitive fuzzy sets, the total of the degrees of membership and non-membership can be more than 1, but their squares cannot. This allows for defining these uncertainties more comprehensively. Some definitions of Pythagorean fuzzy sets are given below [7].

Let X be a universal set and P the Pythagorean fuzzy set be the object of this universal set. The object P is expressed as in Equation (1): [8, 34]

$$\mathrm{P} = \left\{< \mathrm{x}, \mathrm{P}\left(\mu_P(\mathrm{x}), v_P(\mathrm{x})\right) > \middle| \mathrm{x} \in \mathrm{X}\right\}. \tag{1}$$

Here $\mu(\mathrm{x})\colon \mathrm{x} \to [0,1]$ denotes membership degree and $v(\mathrm{x})\colon \mathrm{x} \to [0,1]$ denotes non-membership degree.

Definition 1: The degree to which an element x in the universal set *X* is a member of the set *P*, which is a subset of the same universal set, is indicated by 0 or 1. If $\mu(\mathrm{x}) = 1$, then x is interpreted as a member of *P*, and for each x ∈ X,

$$0 \leq \mu_P(\mathrm{x})^2 + v_P(\mathrm{x})^2 \leq 1\,. \tag{2}$$

The hesitation index for any Pythagorean fuzzy set *P* and is calculated by the formula in Equation (3):

$$\pi_P(x) = \sqrt{1 - \mu^2{}_P(x) - v^2{}_P(x)}. \tag{3}$$

Definition 2: Let $\beta_1 = (\mu_{\beta_1}, v_{\beta_1})$ and $\beta_2 = (\mu_{\beta_2}, v_{\beta_2})$ be two Pythagorean fuzzy numbers and the operations that can be done with these numbers for $\lambda > 0$ are defined as follows:

$$\beta_1 \oplus \beta_2 = P(\sqrt{{\mu_{\beta_1}}^2 + {\mu_{\beta_2}}^2 - {\mu_{\beta_1}}^2{\mu_{\beta_2}}^2}, v_{\beta_1}v_{\beta_2}) \quad (4)$$

$$\beta_1 \otimes \beta_2 = P(\mu_{\beta_1}\mu_{\beta_2}, \sqrt{{v_{\beta_1}}^2 + {v_{\beta_2}}^2 - {v_{\beta_1}}^2{v_{\beta_2}}^2}) \quad (5)$$

$$\lambda\beta_1 = \mathrm{P}(\sqrt{1 - (1 - {\mu_{\beta_1}}^2)^\lambda}, (v_{\beta_1})^\lambda), \lambda > 0 \quad (6)$$

$${\beta_1}^\lambda = \mathrm{P}(\left(\mu_{\beta_1}\right)^\lambda), \sqrt{1 - (1 - {v_{\beta_1}}^2)^\lambda}, \lambda > 0. \quad (7)$$

Definition 3: If $\beta_1 = (\mu_{\beta_1}, v_{\beta_1})$ and $\beta_2 = (\mu_{\beta_2}, v_{\beta_2})$ are two Pythagorean fuzzy numbers, the natural “quasi-ordering” of Pythagorean fuzzy numbers is as follows:
$\beta_1 \geq \beta_2$ will occur if and only if it satisfies the conditions for $\mu_{\beta_1} \geq \mu_{\beta_2}$ and $v_{\beta_1} \leq v_{\beta_2}$.

To compare the size of two Pythagorean fuzzy numbers, the calculation function developed by Zhang and Xu [34] is as follows:

$$\mathrm{s}(\beta_1) = (\mu_{\beta_1})^2 - (v_{\beta_1})^2 \,. \quad (8)$$

Definition 4: Based on the calculation function proposed for Pythagorean fuzzy numbers in the definition above, the rules defined for comparing two Pythagorean fuzzy numbers are given below:
1) If $\mathrm{s}(\beta_1) < \mathrm{s}(\beta_2)$, then $\beta_1 \prec \beta_2$
2) If $\mathrm{s}(\beta_1) > \mathrm{s}(\beta_2)$, then $\beta_1 \succ \beta_2$
3) If $s(\beta_1) = \mathrm{s}(\beta_2)$, then $\beta_1 \sim \beta_2$.

3.3. The Proposed Approach

This paper offers an integrated MCDM approach with two phases to re-assess. The PFAHP is used to weight the criteria in the first phase. Using the PFCOPRAS technique, 25 lifting equipment operations were ranked in the second phase according to risk priority. Figure 2 provides a framework for the proposed integrated approach.

In the first phase, the criteria (risk parameters) weight calculated by the PFAHP. AHP is a method in which both quantitative and qualitative variables are evaluated together [35]. Although the AHP includes the subjective thoughts of the decision makers, the use of net values cannot fully reflect the thoughts of the decision makers when making comparisons. For this reason, Pythagorean fuzzy and AHP are combined. In PFAHP method, unlike the traditional AHP method, linguistic values are used instead of net values [36]. The AHP method can be integrated into the Pythagorean Fuzzy Sets, just like several other MCDM techniques. To establish the Fine-Kinney risk parameter (probability, exposure, and consequence) weights, interval-valued PFAHP is used. The interval valued PFAHP algorithm consists of the following six steps [29]:

Step-1: Creation of the pairwise comparison matrix
The first step is the creation of a pair comparison matrix using nine-point language variables.

$R\left(r_{jk}\right)_{n\times n}$ $j, k = j$ th or k th criteria (P, E, C values) $\forall j, k = \{1,2,\ldots,n\}$
Step-2: Creation of the difference matrix
The second step is the creation of a difference matrix using Equations (9) and (10).

$$D\left(d_{jk}\right)_{n\times n}$$

$$d_{jkU} = \mu_{jkU}^2 - v_{jkL}^2 \tag{9}$$

$$d_{jkL} = \mu_{jkL}^2 - v_{jkU}^2 \ . \tag{10}$$

Step-3: Creation of the interval multiplicative matrix

The third step is the creation of a multiplicative matrix using Equations (11) and (12)

$$s_{jkU} = \sqrt{1000^{d_U}} \tag{11}$$

$$s_{jkL} = \sqrt{1000^{d_L}}. \tag{12}$$

Step-4: Calculation of determinacy value

The fourth step is the calculation of the degrees of hesitation using Equation (13)

$$\tau_{jk} = 1 - (\mu_{jkU}^2 - \mu_{jkL}^2) - (v_{jkU}^2 - v_{jkL}^2). \tag{13}$$

Step-5: Calculation of the matrix of weights

The fifth step is the calculation of the unnormalized weights using Equation (14)

$$t_{jk} = \left(\frac{s_{jkL}+s_{jkU}}{2}\right)\tau_{jk}. \tag{14}$$

Step-6: Calculation of criterion weights

The sixth step is the calculation of the criterion weights using Equation (15)

$$w_j = \frac{\sum_{k=1}^{n} t_{jk}}{\sum_{j=1}^{n}\sum_{k=1}^{n} t_{jk}}\ . \tag{15}$$

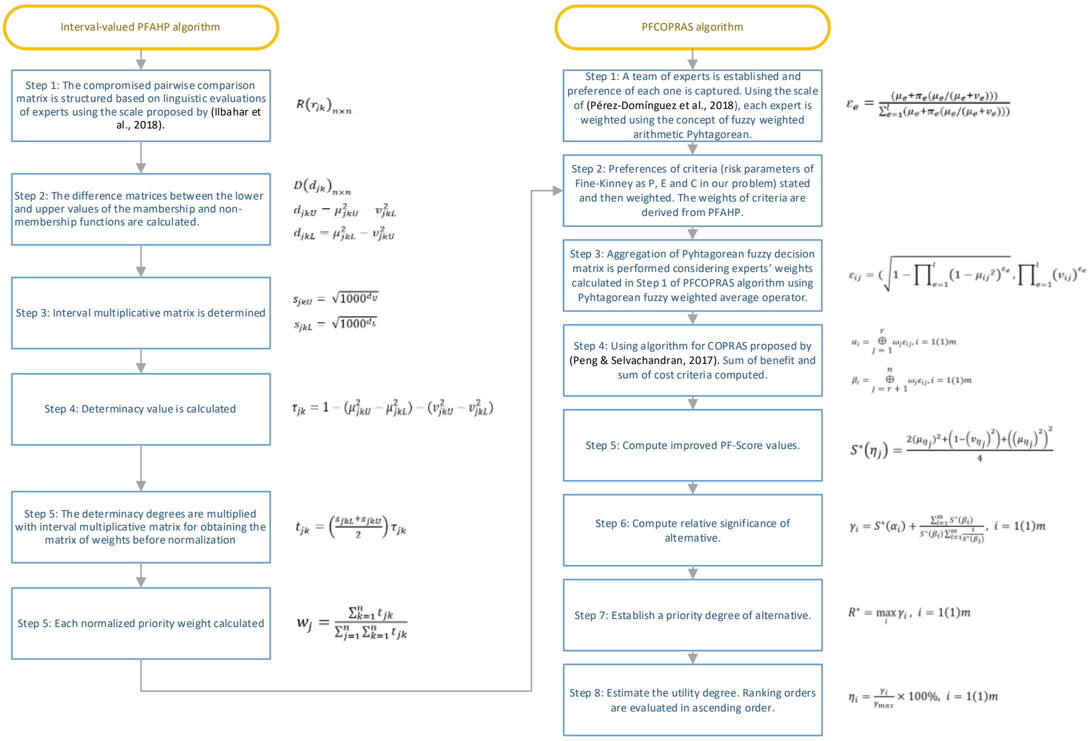


Figure 2. *Flow chart of proposed approach*

The ranking of risks based on Fine-Kinney's three risk parameters is the focus of the second phase of the integrated method. In the second phase, 25 hazards of lifting equipment in the energy and investment sector are ranked using the PFCOPRAS method. The method rates the benefits and importance of the criteria to evaluate the alternatives. In MCDM problems, COPRAS is typically employed as the second tool [37].

Zavadskas and Kaklauskas [38] initially introduced the COPRAS technique for project evaluation in the literature. The PFCOPRAS algorithm consists of the following eight steps:

Step-1: Computation of decision experts (DEs) weights
As a first step, calculate DEs' weights using Equation (16) proposed by Pérez-Domínguez et al. [39].
Let $DM_e = \mu_e, v_e, \pi_e$ be a Pythagorean fuzzy number

$$\varepsilon_e = \frac{(\mu_e+\pi_e(\mu_e/(\mu_e+v_e)))}{\sum_{e=1}^{l}(\mu_e+\pi_e(\mu_e/(\mu_e+v_e)))} \tag{16}$$

e = e th defines expert $\forall e = \{1,2,\dots,l\}$.

Step-2: Evaluation of criteria weights
The preferences of the criteria (Fine-Kinney risks parameters) were calculated using the PFAHP method.

Step-3: Construction of the aggregated decision matrix
At this stage, the aggregate decision matrix is created using Equation (17)

$$\varepsilon_{ij} = (\sqrt{1-\prod_{e=1}^{l}\left(1-\mu_{ij}{}^{2}\right)^{\varepsilon_e}}, \prod_{e=1}^{l}\left(v_{ij}\right)^{\varepsilon_e} \tag{17}$$

i = i th defines alternative $\forall i = \{1,2,\dots,m\}$.

Step-4: Sum of criteria values in terms of costs and benefits
Using Equations (18) and (19), the sum of the cost and benefit criteria values is calculated.

$$\alpha_i = \bigoplus_{j=1}^{l} \omega_j\varepsilon_{ij}, i = 1(1)m, \text{(For benefit-type)} \tag{18}$$

$$\beta_i = \bigoplus_{j=l+1}^{n} \omega_j\varepsilon_{ij}, i = 1(1)m, \text{(For cost-type)}\ . \tag{19}$$

Step-5: Calculation of PF-score
Using Equation (20) PF-score is computed

$$S^*\left(\eta_j\right) = \frac{2(\mu_{\eta_j})^2+\left(1-\left(v_{\eta_j}\right)^2\right)+\left(\left(\mu_{\eta_j}\right)^2\right)^2}{4}. \tag{20}$$

Step-6: Calculation of relative significance values
Using Equation (21) relative significance values is calculated

$$\gamma_i = S^*(\alpha_i) + \frac{\sum_{i=1}^{m} S^*(\beta_i)}{S^*(\beta_i)\sum_{i=1}^{m}\frac{1}{S^*(\beta_i)}}, i = 1(1)m. \tag{21}$$

Step-7: Calculation a priority degree of options
Calculate the priority of the options using Equation (22)

$$R^* = \max_i \gamma_i\,,\ i = 1(1)m. \tag{22}$$

Step-8: Estimation of the utility degree

Estimate the utility degree using Equation (23)

$$\eta_i = \frac{\gamma_i}{\gamma_{max}} \times 100\%,\ i = 1(1)m\ . \tag{23}$$

The alternative with a performance index (Pi) of 100 represents the best alternative. Alternatives are sorted from largest to smallest according to their performance index (Pi) values [40].

Using an integrated approach combining PFAHP and PFCOPRAS has several benefits compared to traditional methods such as Fine-Kinney or AHP-COPRAS. Firstly, the proposed approach takes into account both qualitative and quantitative factors when assessing risk, providing a more comprehensive and accurate evaluation. This approach also considers the uncertainties and vagueness of risk factors by using Pythagorean fuzzy numbers, which provides a more realistic and practical representation of the risk. Secondly, the proposed approach uses a hierarchical decision-making framework that ensures consistency and transparency in the risk assessment process. The weights of the risk factors are determined through a systematic and rigorous approach, which makes the results more reliable and credible. However, there are some potential drawbacks to this approach. One issue is that the use of Pythagorean fuzzy numbers can be more complex and time-consuming than traditional methods, which could be a barrier for some decision-makers. Additionally, the proposed approach requires a certain level of expertise in both PFAHP and PFCOPRAS, which could limit its applicability in certain contexts. Overall, the proposed integrated approach provides a more robust and comprehensive evaluation of risk compared to traditional methods, but its complexity and expertise requirements may limit its wider use in practice.

4. APPLICATION

In this section, the proposed Fine-Kinney-based occupational hazard evaluation and PFAHP and PFCOPRAS combination are applied for the weight of the criteria and ranking of the lifting equipment activities according to risk priorities.

4.1. Case Study

The application was made for the energy distribution and investment sector. The risks of lifting vehicles used in this sector have been examined. In this context, the opinions of seven experts with high experience in the sector were taken. Detailed information about the titles and experiences of the experts is given in Table 1.

Table 1. *Titles and experiences of OHS expert*

Expert ID	Title	Years of Experience
E-1	OHS expert (class B)	5
E-2	OHS expert	5
E-3	OHS expert	10
E-4	OHS expert (class A)	10
E-5	OHS expert (class A)	9
E-6	OHS expert (class A)	5
E-7	OHS expert (class B)	5

Potential hazards and corresponding risks have been identified for hoists used in the energy distribution and investment sector. The 25 hazards identified by the expert team are shown in Table 2.

Table 2. *Identified hazards in working area and definitions*

Hazard ID	Field of activity	Source of hazard	Consequence of hazard
H-1	Working with Lifting Tools (General)	The periodic checks of the vehicles are not carried out	Increased workforce loss, increased number of accidents, injury and death
H-2	Working with Mobile Crane	Material drop from height	Injury and death
H-3	Working with the Crane	Uncontrolled movement of crane hooks	Occupational accident, injury and death
H-4	Working with Platform Basket	Dangerous and careless work of employees	Occupational accident, injury and death

H-5	Working with Chain Blocks	Safety precautions not taken when working with chain blocks	Occupational accident, injury and death
H-6	Working with the Crane	Multiple staff are not synchronized	Injury and death
H-7	Working with Platform Basket	Platform basket tipping	Accident, property damage, injury and death
H-8	Working with the forklift	Forklift tipping	Injury and death
H-9	Working with the Crane	Lack of adequate lighting in crane use	Injury and death
H-10	Working with Mobile Crane	Mobile Crane tipping	Accident, property damage, injury and death
H-11	Working with the Crane	Careless operation of more than one crane in the same area	Accident, property damage, injury and death
H-12	Working with the Crane	Dangerous and careless work of employees	Occupational accident, injury and death
H-13	Working with Platform Basket	Lack of adequate lighting in the working environment	Occupational accident, injury and death
H-14	Working with Platform Basket	Material drop from height	Injury and death
H-15	Working with Platform Basket	Employees who do not have a work-at-height report work with the platform basket	Occupational accidents as a result of improper work, injury and death
H-16	Working with the Crane	Unauthorized personnel working	Injury and death
H-17	Working with the Crane	Starting work without checking	Injury and death
H-18	Working with Lifting Tools (General)	Use of vehicles by unlicensed and unauthorized personnel	Accident, property damage, injury and death
H-19	Working with the Crane	Material drop from height	Injury and death
H-20	Working with Lifting Tools (General)	Not using PPE in work done at height	Occupational accident, injury and death
H-21	Working with the forklift	Forklift hitting pedestrians	Occupational accident, injury and death
H-22	Working with Platform Basket	Slippery platform floor	Occupational accident, injury and death
H-23	Working with Lifting Tools (General)	Absence of a fire extinguisher	Injury and death
H-24	Working with lift	Elevator fall, elevator jamming, rope breakage	Injury and death
H-25	Working with the forklift	Forks not tilted down when parked	Occupational accident, injury and death

4.2. Implementation of the PFAHP Algorithm

In this stage, the algorithm shown in Figure 2 illustrates Fine-Kinney's computational procedures to calculate the significance weights of the three risk parameters. Seven experts are requested to explain pairwise assessments of the severity of each danger parameter using the language variables defined in Ilbahar et al. [29]. The Pythagorean fuzzy numbers represent the interval value corresponding to the linguistic variable expressions. In fact, expert assessments of each risk are different, subjective expert judgments need to be collected in the pairwise comparison matrix presented in Table 3.

Table 3. *The pairwise comparison matrix*

	Probability	Exposure	Consequence
Probability	EE	AAI	HI
Exposure	BAI	EE	AAI
Consequence	LI	BAI	EE

The combined compromised pairwise comparison matrix for three Fine-Kinney risk measures is shown in Table 4.

Table 4. *The aggregated compromised pairwise comparison matrix*

	Probability				Exposure				Consequence			
	μL	μU	vL	vU	μL	μU	vL	vU	μL	μU	vL	vU
Probability	0.1965	0.1965	0.1965	0.1965	0.5500	0.6500	0.3500	0.4500	0.6500	0.8000	0.2000	0.3500
Exposure	0.3500	0.4500	0.5500	0.6500	0.1965	0.1965	0.1965	0.1965	0.5500	0.6500	0.3500	0.4500
Consequence	0.2000	0.3500	0.6500	0.8000	0.3500	0.4500	0.5500	0.6500	0.1965	0.1965	0.1965	0.1965

Tables 5 and 6 indicate the difference matrix and interval multiplicative matrix, respectively.

Table 5. *The difference matrix*

	Probability		Exposure		Consequence	
	dL	dU	dL	dU	dL	dU
Probability	0	0	0.1	0.3	0.3	0.6
Exposure	-0.3	-0.1	0	0	0.1	0.3
Consequence	-0.6	-0.3	-0.3	-0.1	0	0

Table 6. *The interval multiplicative matrix*

	Probability		Exposure		Consequence	
	SL	SU	SL	SU	SL	SU
Probability	1	1	1.413	2.818	2.818	7.943
Exposure	0.355	0.708	1	1	1.413	2.818
Consequence	0.126	0.355	0.355	0.708	1	1

The determinacy value matrix and matrix of weights before normalization are shown in Tables 7 and 8, respectively.

Table 7. *The determinacy value matrix*

	Probability	Exposure	Consequence
Probability	1.000	0.800	0.700
Exposure	0.800	1.000	0.800
Consequence	0.700	0.800	1.000

Table 8. *The matrix of weights before normalization*

	Probability	Exposure	Consequence
Probability	1.000	1.692	3.767
Exposure	0.425	1.000	1.692
Consequence	0.168	0.425	1.000

As a result, PFAHP can calculate the normalized priority risk parameter weights, as illustrated in Figure 3

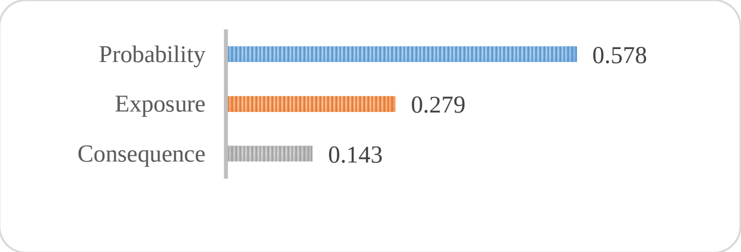


Figure 3. *The weights of three risk parameters*

4.3. Implementation of PFCOPRAS Algorithm

In the first phase of PFCOPRAS, the weight values of experts are taken. The linguistic scales in Table 9 that were suggested by Pérez-Domínguez et al. [39] were used to evaluate the preference criteria of each expert.

Table 9. *Pythagorean fuzzy sets for evaluating the experts*

Linguistic Term	PFNs (μ, v)	
Very Insignificant (VI)	0.10	0.90
Insignificant (I)	0.35	0.60
Average (A)	0.50	0.45
Imperative (Im)	0.75	0.40
Very Significative (Vs)	0.90	0.10

The weight of each expert is calculated using the formulations given in Figure 2. Thus, the weights of the experts are given in Table 10.

Table 10. *The weights of experts*

Expert ID	Linguistic Term	Weight
E-1	A	0.123276559
E-2	A	0.123276559
E-3	VS	0.177663327
E-4	VS	0.177663327
E-5	Im	0.151567110
E-6	A	0.123276559
E-7	A	0.123276559

The second phase concerns the identification of risk parameter weights. At the PFAHP stage, this process is completed, and weights are obtained. The significance weights of probability, exposure, and consequence values are calculated as 0.578, 0.279, and 0.143 respectively based on PFAHP results. This stage assesses the most significant risk parameter, probability (P=0.578), the second most significant risk parameter, exposure (E=0.279), and the third most significant risk parameter, consequence (C=0.143).

The third phase, the Pythagorean fuzzy decision matrix for hazards based on expert weights is aggregated, which is computed using a PFWA operator. The scale suggested by Pérez-Domínguez et al. [39] assesses potential hazards. Table 11 shows the Pythagorean nine-point fuzzy language scale for hazard assessment based on the three Fine-Kinney risk parameters described above.

Table 11. *The nine-point Pythagorean fuzzy linguistic scale*

Linguistic term	**PFNs (μ, v)**	
Extremely low (EL)	0.10	0.99
Very little (VL)	0.10	0.97
Little (L)	0.25	0.92
Middle little (ML)	0.40	0.87
Middle (M)	0.50	0.80
Middle high (MH)	0.60	0.71
Big (B)	0.70	0.60
Very tall (VT)	0.80	0.44
Tremendously high (TH)	1.00	0.00

The aggregated Pythagorean fuzzy decision matrix is displayed in Table 12. It was created based on the seven expert reviews.

Table 12. *The aggregated Pythagorean fuzzy decision matrix*

	Probability (0.578)		Exposure (0.279)		Consequence (0.143)	
Hazard ID	μ	v	μ	v	μ	v
H-1	0.23	0.94	0.18	0.95	0.68	0.61
H-2	0.13	0.97	0.35	0.89	0.76	0.51
H-3	0.16	0.96	0.16	0.96	0.63	0.66
H-4	0.53	0.76	0.30	0.91	0.68	0.61
H-5	0.21	0.94	0.16	0.96	0.67	0.62
H-6	0.21	0.95	0.16	0.96	0.55	0.00
H-7	0.16	0.96	0.16	0.96	0.74	0.53
H-8	0.13	0.97	0.16	0.96	0.75	0.51
H-9	0.17	0.97	0.16	0.96	0.67	0.63
H-10	0.10	0.98	0.16	0.96	0.76	0.50
H-11	0.16	0.96	0.16	0.96	0.61	0.00
H-12	0.21	0.94	0.33	0.90	0.76	0.50
H-13	0.10	0.99	0.16	0.96	0.72	0.56
H-14	0.17	0.96	0.27	0.92	0.72	0.56
H-15	0.10	0.99	0.16	0.96	0.76	0.50
H-16	0.17	0.97	0.16	0.96	0.67	0.00
H-17	0.30	0.92	0.20	0.94	0.77	0.48
H-18	0.17	0.97	0.16	0.96	0.67	0.00
H-19	0.17	0.97	0.16	0.96	0.76	0.50
H-20	0.39	0.87	0.24	0.93	0.77	0.48
H-21	0.13	0.98	0.16	0.96	0.56	0.00
H-22	0.17	0.97	0.37	0.87	0.68	0.61
H-23	0.10	0.98	0.16	0.96	0.55	0.75
H-24	0.10	0.98	0.10	0.98	0.57	0.00
H-25	0.10	0.98	0.21	0.95	0.62	0.67

In the last step, the sum of the benefit and cost criteria are calculated using the COPRAS algorithm proposed by Peng & Selvachandran [20]. The improved PF-Score S*(+i) values are calculated. The relative importance values of the alternatives, which are symbolized by Qi, is calculated. The utility degree (li) is estimated. The result of the PFCOPRAS method for each hazard, S*(+i), Qi, li were calculated and shown in Table 13.

Table 13. *The result of the PFCOPRAS method*

Hazard ID	μ+	v+	S*(+i)	Qi	li
H-1	0.348	0.885	0.119	0.119	38.904
H-2	0.392	0.862	0.147	0.147	48.201
H-3	0.300	0.907	0.091	0.091	29.913
H-4	0.510	0.774	0.247	0.247	81.128
H-5	0.335	0.891	0.110	0.110	36.240
H-6	0.286	0.000	0.293	0.293	96.055
H-7	0.357	0.882	0.123	0.123	40.505
H-8	0.358	0.884	0.123	0.123	40.265
H-9	0.320	0.912	0.096	0.096	31.484
H-10	0.359	0.887	0.122	0.122	39.905
H-11	0.289	0.000	0.293	0.293	96.270
H-12	0.409	0.851	0.159	0.159	52.309
H-13	0.332	0.901	0.105	0.105	34.547
H-14	0.364	0.880	0.127	0.127	41.744
H-15	0.359	0.888	0.121	0.121	39.816
H-16	0.323	0.000	0.305	0.305	100.000
H-17	0.423	0.843	0.170	0.170	55.702
H-18	0.323	0.000	0.305	0.305	100.000
H-19	0.373	0.876	0.132	0.132	43.422
H-20	0.466	0.818	0.203	0.203	66.729
H-21	0.261	0.000	0.285	0.285	93.588
H-22	0.370	0.880	0.129	0.129	42.413
H-23	0.249	0.939	0.061	0.061	20.086
H-24	0.250	0.000	0.282	0.282	92.613
H-25	0.292	0.920	0.083	0.083	27.132

4.4. Comparison and Sensitivity Analysis

In this section, the suggested integrated PFAHP and PFCOPRAS method results are compared with classical Fine-Kinney and Fine-Kinney-based AHP-COPRAS method values. The hazards in the lifting equipment of the energy distribution and investment sector were ranked using Classic Fine-Kinney, AHP-COPRAS, and the proposed integrated approach. According to the ranking of hazards, Table 14 compares the results of different approaches.

Depending on the test results for the proposed approach, the riskiest hazards are H-16 (Unauthorized personnel working) and H-18 (Use of vehicles by unlicensed and unauthorized personnel), the second most important risky hazard is obtained as H-11 (Careless operation of more than one crane in the same area), the third most significant risky hazard is H-6 (Multiple staff are not synchronized), the fourth most critical risky hazard is H-21 (Forklift hitting pedestrians). On the other hand, the least significant risky hazard is also determined as H-23 (Absence of a fire extinguisher), the second least significant risky hazard is H-25

(Forks not tilted down when parked) and the third least significant risky hazard is H-3 (Uncontrolled movement of crane hooks). In classical Fine-Kinney and Fine-Kinney AHP-COPRAS, while H-4 (Dangerous and careless work of employees in Platform Basket) is the most critical hazard among twenty-five hazards, it ranks in sixth for the suggested approach. While H-12 (Dangerous and careless work of employees in Crane) is the second critical risk in the classical Fine-Kinney and Fine-Kinney AHP-COPRAS, it ranks ninth in the suggested approach. While H-20 (Not using PPE in work done at height) is the third critical risk in the classical Fine-Kinney, it ranks fourth in the Fine-Kinney AHP-COPRAS, it ranks seventh in the proposed approach. H-23 (Absence of a fire extinguisher) is consistently ranked as the least major hazard across all approaches. In classical Fine-Kinney and proposed approach, while H-25 (Forks not tilted down when parked) is the second least critical hazard among twenty-five hazards, it ranks third least in the Fine-Kinney-Based AHP-COPRAS.

Case-1 uses the classical Fine-Kinney method and multiplied three risk parameters. The detail of the method is given in section 3. Case-2 uses the Fine-Kinney-based AHP-COPRAS method. Case-3 (the proposed approach) uses the Fine-Kinney-based Pythagorean fuzzy AHP-COPRAS integrated method. The weights for use in Case 2 were found (using AHP) to be 0.539, 0.297, and 0.164 for probability (P), exposure (E), and consequence (C), respectively. The weights of the base are case found and given in Figure 3. The results according to the ranking order of different approaches are given in Table 14. Moreover, the outcomes are given visually shown in Figure 4 for ranking order outcomes of three approaches.

Table 14. *Final ranking results of each approach*

	Ranking The Risks		
Hazard ID	Classical Fine-Kinney	Fine-Kinney-Based AHP-COPRAS	The Proposed Approach
H-1	7	5	18
H-2	6	6	10
H-3	15	8	22
H-4	1	1	6
H-5	14	12	19
H-6	5	7	3
H-7	13	14	14
H-8	19	20	15
H-9	17	16	21
H-10	21	21	16
H-11	12	15	2
H-12	2	2	9
H-13	23	22	20
H-14	10	11	13
H-15	22	24	17
H-16	18	19	1
H-17	4	3	8
H-18	8	10	1
H-19	9	9	11
H-20	3	4	7
H-21	11	13	4
H-22	20	17	12
H-23	25	25	24
H-24	16	18	5
H-25	24	23	23

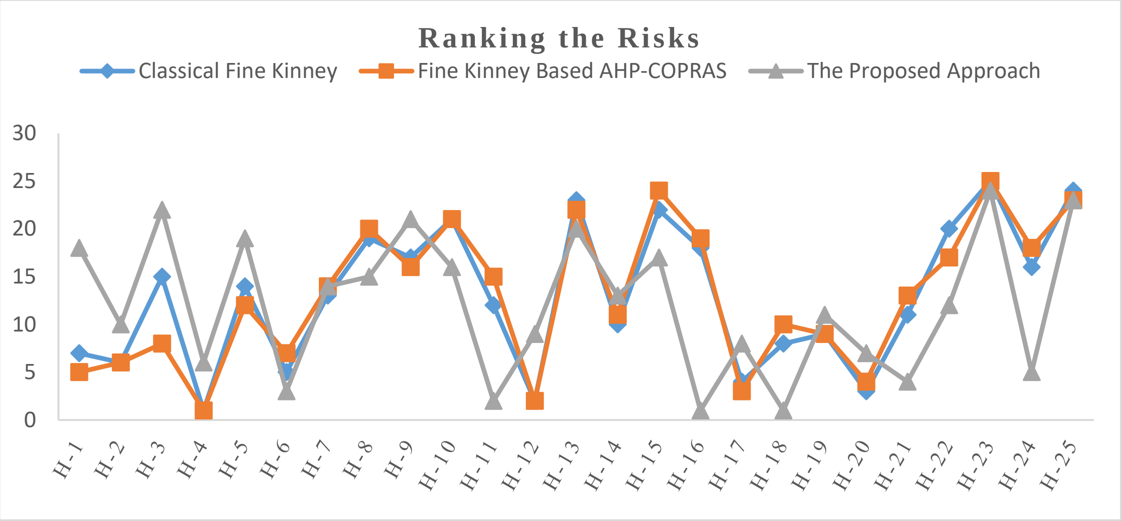


Figure 4. *The outcomes of the benchmarking study.*

The proposed approach was also validated using a sensitivity analysis. When dealing with uncertainty, decision-makers can use this study to learn more about the significance of risk parameters. The weight of the risk factors of the proposed case was compared with the weight of the risk factors of four additional cases proposed by Gul et al. [9]. The weight vectors for the Fine-Kinney parameters created for sensitivity analysis are shown in Table 15.

Table 15. *The weight vectors of the Fine-Kinney parameters designed for sensitivity analysis*

Case for risk parameter weights	Weight of risk parameter in Fine-Kinney		
	Probability	Exposure	Consequence
Base case	0.578	0.279	0.143
Case 1: Gul et al. (2021)	0.289	0.293	0.418
Case 2: Gul et al. (2021)	0.250	0.200	0.550
Case 3: Equal weight	0.333	0.333	0.333
Case 4: Gul et al. (2021)	0.400	0.400	0.200

Table 16 and Figure 5 indicate the outcomes for ranking risks for different cases

Table 16. *Ranking order changes in times of parameters' weights changes*

	Sensitivity Analysis				
Hazard ID	Base case	Case-1	Case-2	Case-3	Case-4
H-1	18	19	19	19	18
H-2	10	9	6	10	10
H-3	22	22	22	22	22
H-4	6	11	15	8	6
H-5	19	20	20	20	20
H-6	3	4	12	3	3
H-7	14	15	14	15	17
H-8	15	14	11	14	16
H-9	21	21	21	21	21
H-10	16	13	9	13	15
H-11	2	2	5	2	2
H-12	9	8	4	9	9

H-13	20	17	17	18	19
H-14	13	16	16	16	13
H-15	17	12	8	12	14
H-16	1	1	1	1	1
H-17	8	7	3	7	8
H-18	1	1	1	1	1
H-19	11	10	7	11	11
H-20	7	3	2	6	7
H-21	4	5	13	4	4
H-22	12	18	18	17	12
H-23	24	24	24	24	24
H-24	5	6	10	5	5
H-25	23	23	23	23	23

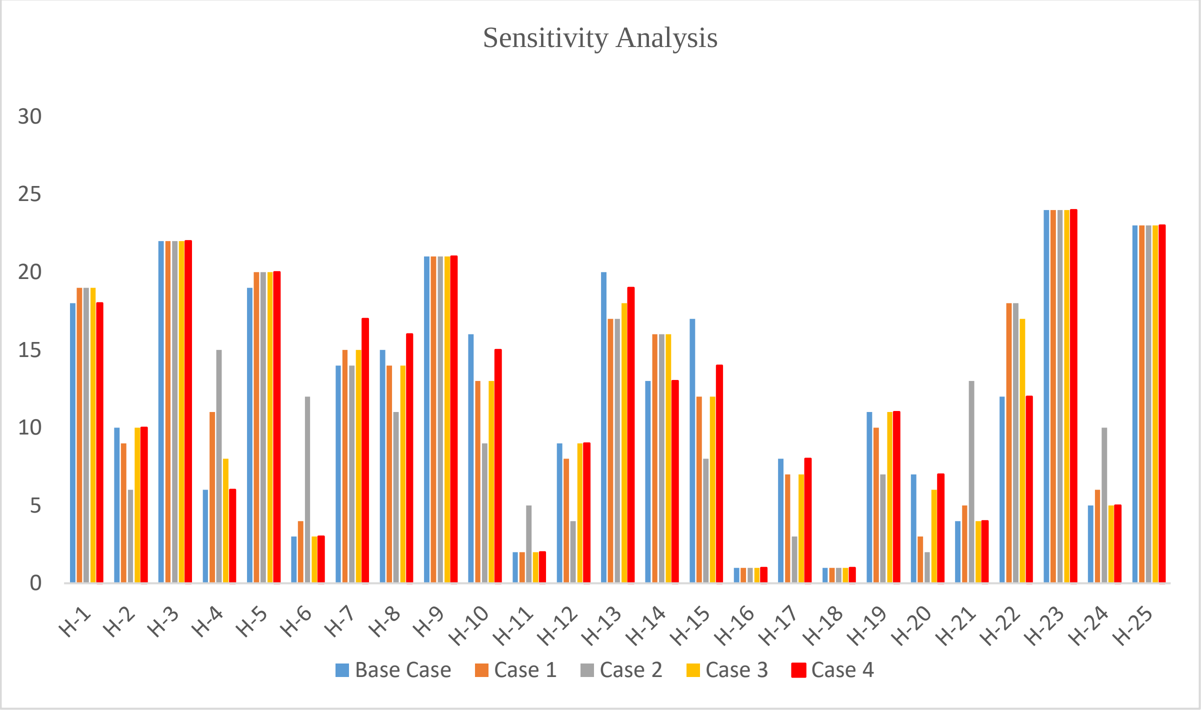


Figure 5. *Results of sensitivity analysis*

As seen in Figure 5 in all five cases the most significant hazard are H-16 (Unauthorized personnel working) and H-18 (Use of vehicles by unlicensed and unauthorized personnel). H-11(Careless operation of more than one crane in the same area) is the second most important risky hazard in all cases except case-3. In addition, in all five cases, H-23 (Absence of a fire extinguisher) is the least significant hazard and is classified in the last order. Furthermore, in all five cases, H-25 (Forks not tilted down when parked) is the second least important hazard and is classified in the last order. Additionally, in all five cases, H-3 (Uncontrolled movement of crane hooks) is the third least important hazard and is classified in the last order. With a few minor exceptions, the ranking orders of hazards are generally the same in all five cases.

The numerical results obtained from the proposed approach can be presented in a clear and concise manner, which makes it easier for authorities and decision-makers in the industry to interpret and make informed decisions. The proposed approach provides a comprehensive ranking of hazards based on their level of criticality, which allows decision-makers to prioritize the implementation of safety measures and allocate resources accordingly. One of the main advantages of the proposed approach is its ability to take into account the subjective judgments of experts and stakeholders in the industry. This is achieved through the use of the AHP and COPRAS methods, which provide a structured and transparent way of integrating the opinions and preferences of different stakeholders into the decision-making process. As a result, the proposed approach can lead to more effective and efficient safety measures that are tailored to the specific needs and circumstances of the industry. In addition, the proposed approach can be used to identify the underlying causes of hazards and to develop targeted interventions that address these root causes. This can help to reduce the frequency and severity of accidents and improve overall safety performance in the industry.

Overall, the proposed approach is likely to be preferred by the industry due to its ability to provide a systematic and transparent way of assessing hazards and prioritizing safety measures. It also allows for the integration of subjective judgments and stakeholder preferences, which can lead to greater buy-in and support from those affected by safety decisions.

5. CONCLUSION

People need energy to maintain daily life. Electricity is one of the major ones. Electricity is not only important in human life, but also contains vital risks for those working in that sector. The use of effective risk assessment methods is very important to prevent the risks associated with work performed in the electricity sector, where the vital risk is so significant. This study proposes a novel approach to risk assessment by using the Pythagorean fuzzy set theory and the extended AHP-COPRAS integrated method for risk assessments in the area of industrial health and safety. A case study was conducted on risk assessment for lifting vehicles used in the energy investment and distribution sector. In this study, the risk was assessed by considering the parameters of the classical Fine-Kinney method (probability, exposure, and consequence) and 25 hazards (and their related risks). Seven OHS specialists' reviews resulted in the identification of a total of 25 dangers.

This study suggested a new integrated OSH risk assessment approach using the Fine-Kinney-based Pythagorean fuzzy AHP-COPRAS to quantify risk ratings. A case study was conducted for Lifting Equipment of the Energy Distribution and Investment Sector, a new field of research and methodology because of a lack of literature. Other integrated MCDM methods such as SWARA-COPRAS, and Entropy-COPRAS, on Fine-Kinney-based Pythagorean fuzzy environment can be applied to future searches. Therefore, the development of other MCDM methods to be applied like the energy distribution and investment sector will be a useful tool for stakeholders who are fighting the dangers.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] Ceylan, H., “Türkiye’deki Elektrik Üretim, İletim ve Dağıtım Tesislerinde Meydana Gelen İş Kazalarının Analizi”, Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi, 4(2): 30–42, (2012).

[2] Aslan, İ., and Çelik, Y., “Elektrik Dağıtım Sektöründe Çalışanların İş Sağlığı ve Güvenliği İncelemesi: Muş, Bitlis ve Van İlleri Uygulaması”, Çalışma İlişkileri Dergisi, 1: 130–145, (2022).

[3] Yönetmelik, “Resmî Gazete” 28512. https://www.resmigazete.gov.tr/eskiler/2012/12/20121229-13.htm, (2012, December 29)

[4] Oz, N. E., Mete, S., Serin, F., and Gul, M., “Risk assessment for clearing and grading process of a natural gas pipeline project: An extended TOPSIS model with Pythagorean fuzzy sets for prioritizing hazards”, Human and Ecological Risk Assessment: An International Journal, 25(6): 1615-1632, (2019).

[5] Fattahi, R., and Khalilzadeh, M., “Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment”, Safety Science, 102: 290-300, (2018).

[6] Gul, M., “A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions”, Human and Ecological Risk Assessment: An International Journal, 24(7): 1723–1760, (2018).

[7] Mete, S., Oz, N. E., Gul, M., Serin, F., and Celik, E., “A Risk Assessment Approach Using Both Stochastic Data and Subjective Judgments”, In Intelligent and Fuzzy Techniques in Big Data Analytics and Decision Making: Proceedings of the INFUS 2019 Conference, Istanbul, (2019).

[8] Yager, R. R., “Pythagorean membership grades in multicriteria decision making”, IEEE Transactions on Fuzzy Systems, 22(4): 958–965, (2014).

[9] Gul, M., Mete, S., Serin, F., and Celik, E., “Fine–Kinney-Based Occupational Risk Assessment Using Interval-Valued Pythagorean Fuzzy VIKOR”, In Fine–Kinney-Based Fuzzy Multi-criteria Occupational Risk Assessment, 45-68, (2021).

[10] Liu, P., “Multi-attribute decision-making method research based on interval vague set and TOPSIS method”, Technological and economic development of economy, 15(3): 453-463, (2009).

[11] Kiritsis, D., Bufardi, A., and Xirouchakis, P., “Multi-criteria decision aid for product end of life options selection”, IEEE International Symposium on Electronics and The Environment, 48–53, (2003).

[12] Yager, R. R., “Properties and applications of Pythagorean fuzzy sets”, In Imprecision and Uncertainty in Information Representation and Processing, 119-136, (2016).

[13] Ma, Z., and Xu, Z., “Symmetric Pythagorean fuzzy weighted geometric/averaging operators and their application in multicriteria decision-making problems”, International Journal of Intelligent Systems, 31(12): 1198-1219, (2016).

[14] Peng, X., and Dai, J., “Approaches to Pythagorean fuzzy stochastic multi-criteria decision making based on prospect theory and regret theory with new distance measure and score function”, International Journal of Intelligent Systems, 32(11): 1187-1214, (2017).

[15] Kahraman, C., Onar, S. C., and Oztaysi, B., “Present worth analysis using pythagorean fuzzy sets”, In Advances in Fuzzy Logic and Technology, 2: 336-342, (2017).

[16] Chen, T. Y., “Remoteness index-based Pythagorean fuzzy VIKOR methods with a generalized distance measure for multiple criteria decision analysis”, Information Fusion, 41: 129-150, (2018).

[17] Garg, H., “Linguistic Pythagorean fuzzy sets and its applications in multi attribute decision-making process”, International Journal of Intelligent Systems, 33(6): 1234-1263, (2018).

[18] Xian, S., Yin, Y., Fu, M., and Yu, F., “A ranking function based on principal-value Pythagorean fuzzy set in multicriteria decision making”, International Journal of Intelligent Systems, 33(8): 1717-1730, (2018).

[19] Rahman, K., Abdullah, S., Ali, A., and Amin, F., “Approaches to multi-attribute group decision making based on induced interval-valued Pythagorean fuzzy Einstein hybrid aggregation operators”, Bulletin of the Brazilian Mathematical Society, New Series, 50(4): 845-869, (2019).

[20] Peng, X., and Selvachandran, G., "Pythagorean fuzzy set: state of the art and future directions", Artificial Intelligence Review, 52: 1873–1927, (2019).

[21] Valipour, A., Yahaya, N., Md Noor, N., Antuchevičienė, J., and Tamošaitienė, J., "Hybrid SWARA-COPRAS method for risk assessment in deep foundation excavation project: An Iranian case study", Journal of Civil Engineering and Management, 23(4): 524–532, (2017).

[22] Yazdani, M., Alidoosti, A., and Zavadskas, E. K., "Risk Analysis of Critical Infrastructures Using Fuzzy Copras", Economic Research-Ekonomska Istraživanja, 24(4): 27–40, (2015).

[23] Popovic, G., Stanujkic, D., and Stojanovic, S., "Investment project selection by applying COPRAS method and imprecise data", Serbian Journal of Management, 7(2): 257–269, (2012).

[24] Büyüközkan, G., and Göçer, F., "A novel approach integrating ahp and copras under pythagorean fuzzy sets for digital supply chain partner selection", IEEE Transactions on Engineering Management, 68(5): 1486–1503, (2021).

[25] Hezer, S., Gelmez, E., and Özceylan, E., "Comparative analysis of TOPSIS, VIKOR and COPRAS methods for the COVID-19 Regional Safety Assessment", Journal of Infection and Public Health, 14(6): 775–786, (2021).

[26] Lu, J., Zhang, S., Wu, J., and Wei, Y., "COPRAS method for multiple attribute group decision making under picture fuzzy environment and their application to green supplier selection" Technological and Economic Development of Economy, 27(2): 369-385, (2021).

[27] Mishra, A. R., Liu, P., and Rani, P., "COPRAS method based on interval-valued hesitant Fermatean fuzzy sets and its application in selecting desalination technology", Applied Soft Computing, 119: 108570, (2022).

[28] Hezam, I. M., Mishra, A. R., Rani, P., Saha, A., Smarandache, F., and Pamucar, D., "An integrated decision support framework using single-valued neutrosophic-MASWIP-COPRAS for sustainability assessment of bioenergy production technologies", Expert Systems with Applications, 211: 118674, (2022).

[29] Ilbahar, E., Karaşan, A., Cebi, S., and Kahraman, C., "A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system", Safety Science, 103: 124–136, (2018).

[30] Rani, P., Mishra, A. R., and Mardani, A., "An extended Pythagorean fuzzy complex proportional assessment approach with new entropy and score function: Application in pharmacological therapy selection for type 2 diabetes", Applied Soft Computing, 94: 106441, (2020).

[31] Kinney, G. F., and Wiruth, A. D., "Practical Risk Analysis for Safety Management", Naval Weapons Center China Lake CA, (1976).

[32] Birgören, B., "Fine Kinney Risk Analizi Yönteminde Risk Analizi Yönteminde Risk Faktörlerinin Hesaplama Zorlukları ve Çözüm Önerileri", International Journal of Research and Development, 9(1), (2017).

[33] Yıldız, A., Ayyıldız, E., Gümüş, A. T., and Özkan, C., "Ülkelerin Yaşam Kalitelerine Göre Değerlendirilmesi İçin Hibrit Pisagor Bulanık Ahp-Topsis Metodolojisi: Avrupa Birliği Örneği", Avrupa Bilim ve Teknoloji Dergisi, 17: 1383–1391, (2019).

[34] Zhang, X., and Xu, Z., "Extension of TOPSIS to Multiple Criteria Decision Making with Pythagorean Fuzzy Sets", International Journal of Intelligent Systems, 29(12): 1061–1078, (2014).

[35] Dağdeviren, M., Akay, D., and Kurt, M., “İş Değerlendirme Sürecinde Analitik Hiyerarşi Prosesi ve Uygulaması”, Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 19(2): 131–138, (2013).

[36] Liu, P. D., and Jin, F., “The trapezoid fuzzy linguistic Bonferroni mean operators and their application to multiple attribute decision making”, Scientia Iranica, 19(6): 1947–1959, (2012).

[37] Ahmad, N., Hasan, M.G., and Barbhuiya, R.K., “Identification and prioritization of strategies to tackle COVID-19 outbreak: A group-BWM based MCDM approach”, Applied Soft Computing, 111: 107642, (2021).

[38] Zavadskas, E.K., and Kaklauskas, A., “The new method of multicriteria evaluation of projects”, Deutsch-Litauisch-Polnisches Kolloqium zum Baubetriebswesen. Hochschule fur Technik, Wirtschaft und Kultur in Leipzig, 3: 3–8, (1996).

[39] Pérez-Domínguez, L., Rodríguez-Picón, L. A., Alvarado-Iniesta, A., Luviano Cruz, D., and Xu, Z., “MOORA under Pythagorean Fuzzy Set for Multiple Criteria Decision Making”, Complexity, 2018: 1-10, (2018).

[40] Sarıçalı, G., and Kundakcı, N., “Ahp ve Copras Yöntemleri ile Otel Alternatiflerinin Değerlendirilmesi”, International Review of Economics and Management, 4(1): 45–66, (2016).