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METHODOLOGIES AND APPLICATION

Investigation and prioritization of risk factors in the collision of two passenger trains based on fuzzy COPRAS and fuzzy DEMATEL methods

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Abstract

Identifying the critical risk factors in train accidents play a vital role in the prevention of their recurrence in the future. However, this is a complex procedure due to the fact that it includes decision making and depends on a large number of relevant factors. In order to resolve this problem, first, this study made an effort to identify the risk factors in the collision of two passenger trains near the "Haft Khan Station" between Semnan and Damghan using the interview technique and the questionnaire survey technique which focused on railway industry experts' opinions and treated them as decision makers. Second, it developed a new framework of risk assessment by prioritizing the identified risk factors in the collision of two passenger trains in order to remedy all of the deficiencies and to improve the safety of railway transportation. Therefore, risk assessment of contributory factors in the collision was based on multi-criteria decision-making approaches such as fuzzy complex proportional assessment (COPRAS) and fuzzy decision making trial and evaluation laboratory (DEMATEL). Accordingly, the study prioritized the risk factors in the collision of two passenger trains including management, individual and environmental conditions, and reaction to events regarding Fuzzy COPRAS and Fuzzy DEMATEL. Finally, sensitivity analysis indicated that the fuzzy DEMATEL had a better performance than the fuzzy COPRAS method. More specifically, it: (a) prioritized the risk factors in a better way due to its higher Spearman's ranking correlation coefficient; (b) facilitated the cause-effect analysis; and (c) was in line with the real collected observation data. In regard to Fuzzy DEMATEL model, the results showed that the critical risk factor with the highest rank was the stop of the front train at the back of the hill. Moreover, the critical risk factor with the lowest rank was the absence of the installation of the Balise system.

Keywords Fuzzy COPRAS · Fuzzy DEMATEL · Multi-decision making · Risk assessment · Train accident

1 Introduction

Rail transport is one of the most popular transport modes, which has been used for over 150 years in the world (Urry 2016). However, the development of technology in rail industry has resulted in widespread accidents (Khairnar et al. 2011). A train accident has serious consequences and leads to high-risk scenarios including fatalities, injuries, and negative effects on the environment. Rail safety management depends on the identification of rail accident frequency and potential risk factors along with their severities (Profillidis 2006; Turla et al. 2019). Reports have indicated that the rate of rail crashes in Iran is much higher than the average global rate of rail crashes due to the density of railways (Salamatnews 2016; Eftekhari et al. 2018). Recognizing the factors which affect the occurrence of train accidents and evaluating risks are the keys to the reduction of the number of fatalities and injuries owing to the importance of the safety of rail transport. These measures prevent the train collisions (Reinach and Viale 2006; Liu et al. 2011; Underwood and Waterson 2014). Train collision and derailment are caused by a sequence of complicated factors including management, individual, and

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environmental conditions (Evans 2011; Asgari 2016; Baradaran 2017).

Therefore, investigating critical risk factors in the collision of passenger trains lead to the reduction of the train collisions and accidents in the future. This issue has motivated researchers and engineers in the safety fields of transport to examine the critical risk factors and practical preventive factors in the railway industry.

1.1 Contribution

The most outstanding contribution of the present study is to identify the practical preventive factors in order to prevent the occurrence of the collision of trains. This study also makes efforts to introduce a risk management framework for reducing risks, increasing the quality of railway services, ensuring the safety of railway transport, and decreasing the cost of correcting critical risk factors.

1.2 Research objectives

The main objectives of the present study are follows: firstly, it is aimed to identify the practical risk factors in the collision of two passenger trains in "Haft Khan" station using questionnaire survey and field observation. Secondly, it adopts two fuzzy multi-criteria decision-making (MCDM) approaches to the evaluation and ranking of risk factors based on the exports' opinions in the field of railway industry.

The second section of the study explains the previous studies which have focused on the conceptual definition of formal risk assessment (FRA), and the risk analysis of railway passenger crashes using Fuzzy COPRAS, and Fuzzy DEMATEL. Furthermore, this section provides a description of the case study and highlights the novelty of the present study. The third section uses a flowchart to explain the methodology of the study, provides information on the sample size and questionnaire size, and introduces Fuzzy COPRAS and Fuzzy DEMATEL. The fourth part presents the results of the study and discusses them. The fifth section compares Fuzzy COPRAS with Fuzzy DEMATEL in terms of sensitivity analysis. Finally, the sixth part draws a conclusion based on the obtained results.

2 Literature review

In this section, research studies about formal safety assessment (FSA) in railway industry are explained. Then, the application of Fuzzy COPRAS and Fuzzy DEMATEL methods in risk assessment and identification of risk factors for railway passenger transportation are taken into consideration. At the end, motivation of the present study regarding the previous works is proposed to facilitate the complexity of evaluating risk factors which contribute to the collision of two trains near the "Haft Khan Station" between Semnan and Damghan.

2.1 Formal safety assessment (FSA)

Formal safety assessment (FSA) is one of the most scientific frameworks which have been recently used to analyze risk and safety based on a scheduled policy (Kontovas and Psaraftis 2009). Risk refers to an event or uncertain situation which has negative or positive impacts on targets (Sekulova and Nedeliakova 2015). Therefore, it is necessary to take account of risk management in order to reduce negative threats and to increase positive effects on targets. The relevant events and reasons need to be examined to identify the risks. Redmill (2002) identified the main causes of risk by designing a cause-effect analysis to prevent the events. Similarly, Ward and Chapman (2003) reported that risk identification was an important criterion for ensuring safety. Fuzzy multi-criteria decision making (MCDM) approaches are adopted as qualitative and quantitative risk assessment tools of the identification and prioritization of the frequency of occurrence and severity (Grassi et al. 2009; Kumru and Kumru 2013).

2.2 Fuzzy COPRAS and fuzzy DEMATEL methods

The previous studies of the risk assessment of railway passenger transportation have focused on risk assessment in train passengers using fuzzy reasoning approach (FRA), and fuzzy analytic hierarchy process (FAHP) (An et al. 2007, 2013). Among other methods, fuzzy COPRAS and fuzzy DEMATEL methods have become particularly prominent in industry in recent years (Bausys et al. 2015; Gitinavard et al. 2017; Seker and Zavadskas 2017; Amoozad Mahdiraji et al. 2018; Can and Toktas 2018; Hatefi 2018; Roozbahani et al. 2020).

Other studies proposed Fuzzy COPRAS and Fuzzy DEMATEL methods to prioritize human, organizational, and environmental factors in railway accidents and to develop a framework of risk assessment (Yazdani et al. 2011; Mentes et al. 2015; Hadj-Mabrouk 2019).

2.3 Motivation

The review of the previous studies shows that they have not investigated critical risk factors which affect the collision of two passenger trains. Additionally, identifying critical risk factors contributing to the collision of two trains is difficult for decision makers to be precisely and accurately measured because of the intangible nature of dangerous and threats and complexity of different criteria. Moreover, Fuzzy COPRAS and Fuzzy DEMATEL have not been applied to prioritize the risk factors as critical and cause-effect factors in the collision of two passenger trains. Furthermore, the previous studies have only examined risk factors for one passenger train collision by adopting one MCDM approach and have not compared it with other MCDM approaches. Considering these issues, the novelty of the present study stems from (a) the investigation of critical risk factors in the collision of two passenger trains based on questionnaire survey and observation field data; (b) the use of two proposed Fuzzy MCDM models (as a preventive approach) for reducing injuries and fatalities based on the modification of risk factors; and (c) the use of an effective model for identifying exact critical risk factors.

2.4 Collision description of the case study

The catastrophic collision of two trains in Haft Khan Station occurred at 7:22 am on Friday November 25, 2016. Semnan-to-Mashhad train collided with Tabriz-to-Mashhad train (which had stopped on the same rails) from behind. There were 542 passengers in two trains. Forty-seven passengers were killed, and 103 people were wounded (Salamatnews 2016; Asgari 2016; Farsnews agency 2016; ISNA 2016). The location of this collision was near the "Haft Khan" station in Semnan–Damghan area with the 35°38′ 0″ N 54°2′ 34″ E coordinates. Figure 1 provides the coordinates of the above-mentioned area. Based on the field information, four wagons were derailed. Moreover, five wagons were burnt. Due to the accident, 12 ambulances, two bus ambulances, and one helicopter were sent to the accident site. The injured were transferred to Damghan Hospital. The bodies of the killed passengers were completely burnt and their identification was very difficult.

3 Research methodology

In the present study, a flowchart is drawn in order to describe the risk assessment methodology for identifying critical risk factors in the collision of two passenger trains based on the Fuzzy MCDD approaches. Figure 2 shows this chart. Before proposing Fuzzy COPRAS and Fuzzy DEMATEL methods, data collection procedure was performed using questionnaire survey and field observation data by visiting Iranian official websites and examining news about the collision.

3.1 Sample size

Table 1 provides the sample size involved for surveying the experts in the collision of two passenger train in Iran. The sample size was estimated for the questionnaire survey using Eq. (1) (Al-Tmeemy et al. 2012):

$$\mathrm{SS} = \frac{Z^2 \times P \times (1 - P)}{C^2} \tag{1}$$

where SS is the calculated sample size, z is z the value for the confidence level, p is the percentage of picking a choice, expressed as decimal, c is the confidence interval. Next, the calculated sample size (SS) was corrected for finite population using Eq. (2):

$$\text{Corrected SS} = \frac{\mathrm{SS}}{1 + \frac{\mathrm{SS}-1}{\mathrm{POP}}} \tag{2}$$

where pop is population. Then, the corrected sample size (Corrected SS) was calculated for the response rate using Eq. (3)

$$\text{Corrected SS for rr} = \mathrm{rr} \times \text{corrected SS} \tag{3}$$

where rr is a response rate.

3.2 Questionnaire survey

In order to detect different risk factors influencing the collision of trains, the present study used a combination of questionnaire surveys based on the review of the related literature and the subjective judgments of highly proficient experts. The questionnaire surveys were designed to obtain the necessary information including risk factors and their effects on the collision of trains. In addition, a field observation was made to link the survey data with the real collision of two passenger trains in Haft-Khan station. This study took advantage of 154 academics, technical, and management experts' knowledge and experience in order to identify and structure the risk factors and to determine the proper risk mitigation strategies. More specifically, in order to carry out the study, the researchers of the present study conducted interviews with the railway experts and examined the relevant standards and theoretical studies in the railway industry including driver risk factors, employee risk factors, dispatch management, equipment management, operation services, seasonal safety risk factors, and other safety risk factors.

Moreover, criteria and sub-criteria were established and described based on the examination of previous studies of factors in the collision of trains for Fuzzy COPRAS and Fuzzy DEMATEL approaches. Table 2 shows these criteria and sub-criteria. The first and the second columns are used for the Fuzzy COPRAS questionnaire. However, the first column is taken into consideration for the Fuzzy DEMATEL questionnaire.

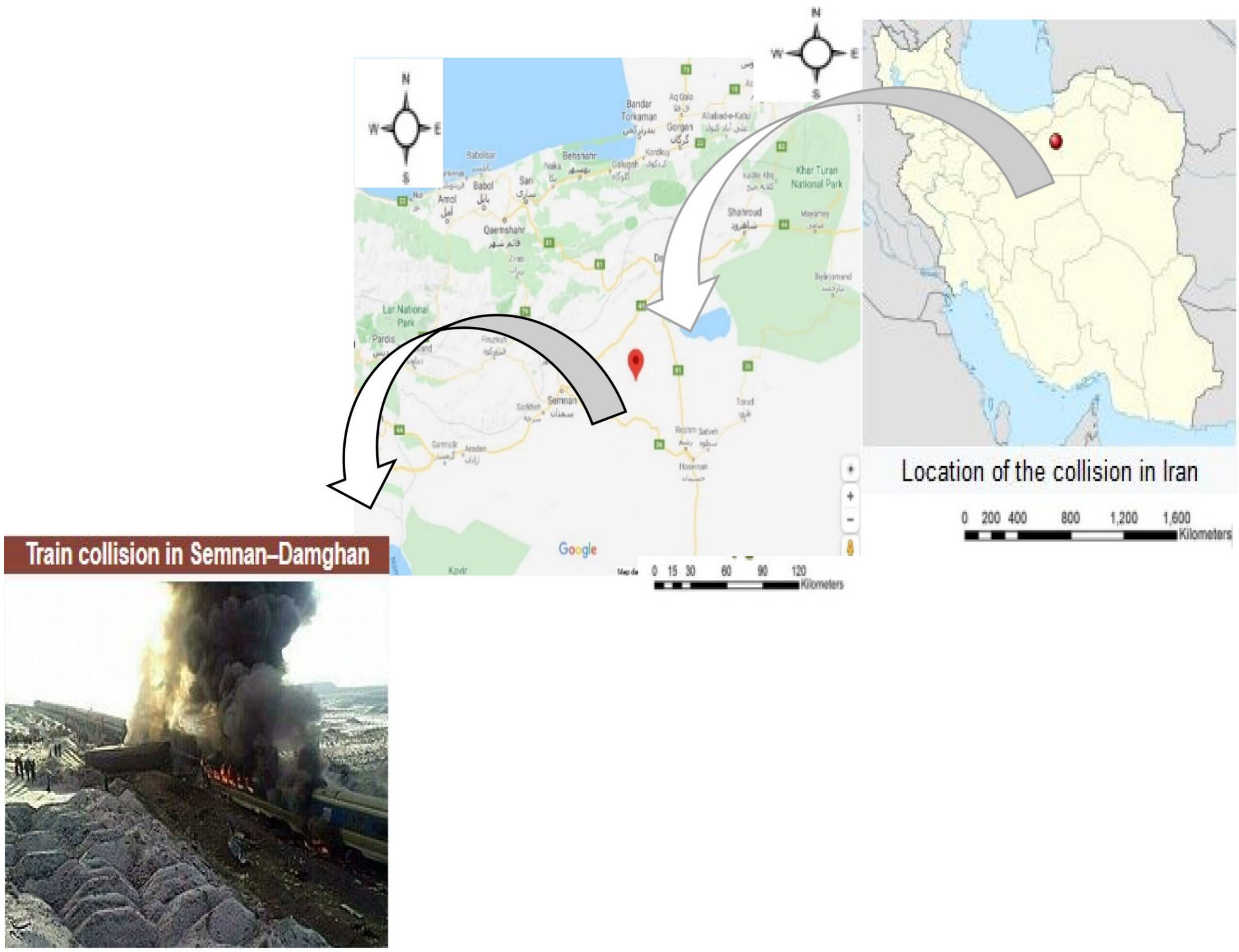

Fig. 1 Location of collision of two passenger trains in Iran

3.3 Fuzzy COPRAS method

COPRAS method is a simple solution for complex problems (Zavadskas and Kaklauskas 1996). According to this method, different alternatives are evaluated and prioritized based on multiple criteria. The criteria and sub-criteria offered by experts are ambiguous and vague in the real world. Consequently, in practice, adopting the linguistic expression approach can be effective and natural for experts and can help them to carry out their assessments. More specifically, a combination of Fuzzy and COPRAS methods is a proper method for prioritizing the existing alternatives when the respondents' verbal phrases are uncertain and ambiguous (Yazdani et al. 2011; Toklu 2017; Ünver and Cil 2020). The Fuzzy COPRAS method is defined in the following steps:

1. Evaluation of alternatives and determination of the importance of criteria and sub-criteria using fuzzy numbers

Decision makers rate alternatives (sub-criteria) by means of the linguistic terms presented in Table 3. Moreover, as shown in Table 4, linguistic terms are used to indicate the weight of the main criteria. As an example, the linguistic term ''Medium importance'' is indicated as (0.25, 0.5, 0.75).

2. Constructing the fuzzy decision matrix

In this step, the fuzzy decision matrix is constructed to denote the importance weight of the criteria, and ratings of the alternatives with respect to criteria in line with experts' opinions in Table 3. Subsequently, the aggregated fuzzy decision matrix is constructed.

It should be mentioned that this matrix is derived from the aggregation of fuzzy decision matrices related to each expert's opinion. The geometric mean score is used to aggregate experts' opinions and to prepare the aggregated fuzzy decision matrix. It is assumed that there are n criteria and m alternatives. Accordingly, the aggregated fuzzy

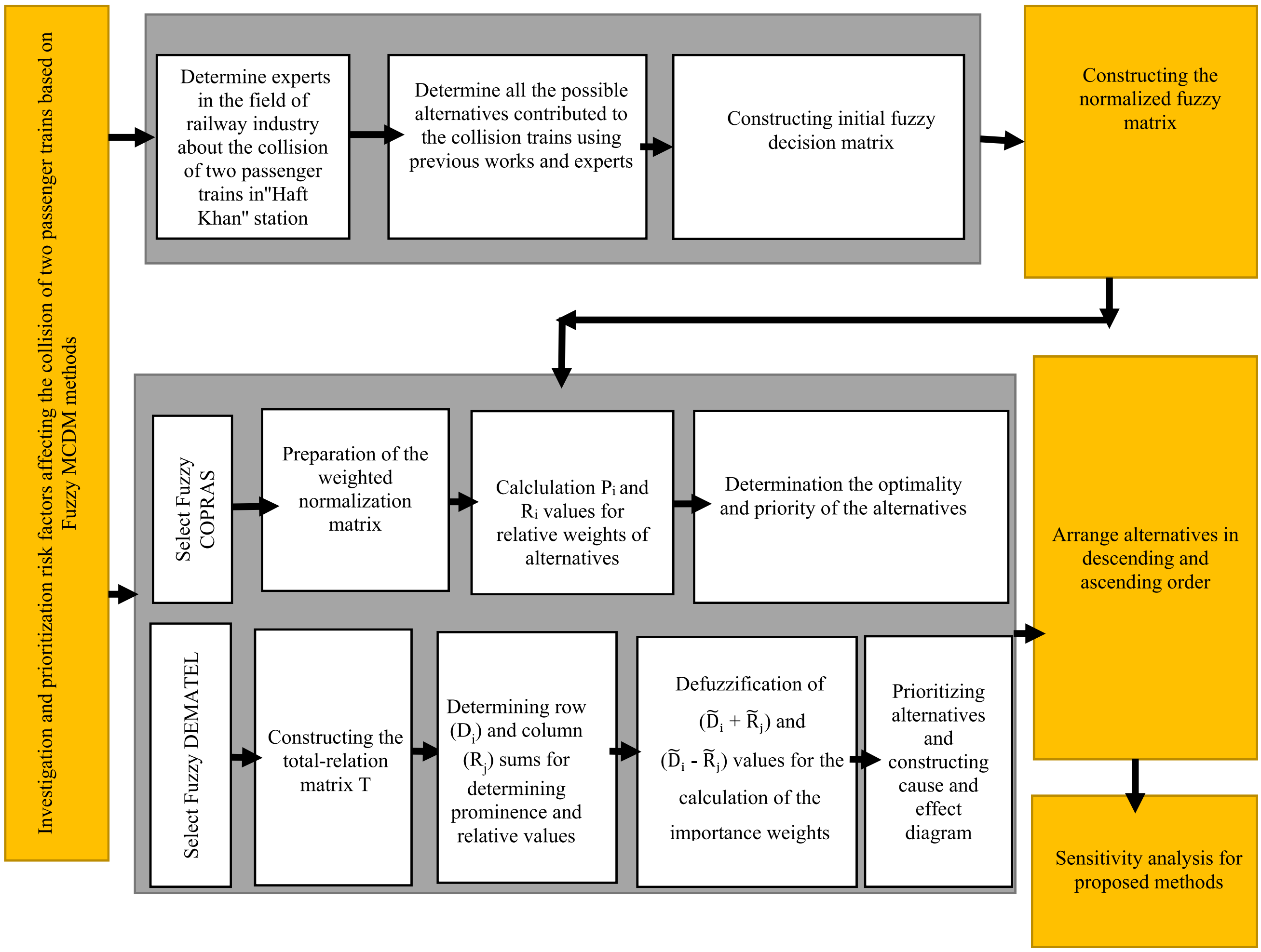

Fig. 2 Flow chart of the research methodology

Table 1 Sample size estimation

Percentage (p)	0.5	
Confidence interval (c)	0.1	0.975
Confidence level and z value	95%	1.96
Response rate (rr)	87.66%	
Population	154	
Total	55	

decision matrix is designed as Eq. (4). Therefore, the final weights of the criteria are determined according to Eq. (5).

$$\tilde{x} = \begin{array}{c} \\ \end{array} \begin{array}{c} C_1 \quad C_2 \quad \ldots \quad C_n \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{12} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{x}_{m1} & \tilde{x}_{m1} & \ldots & \tilde{x}_{mn} \end{bmatrix} \end{array} \begin{array}{c} A_1 \\ A_2 \\ \ldots \\ A_m \end{array} \tag{4}$$

Final weights of the criteria are assumed as follows:

$$\tilde{w} = (\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n) \tag{5}$$

After constructing the aggregated fuzzy decision matrix, in order to construct the defuzzification of the fuzzy decision matrix, the crisp numbers of weights are obtained in the form of the triangular fuzzy number $\tilde{R_i} = (L\tilde{R_i}, M\tilde{R_i}, U\tilde{R_i})$ which is shown in Eq. (6) (Wu et al. 2009).

$$BN\tilde{P_i} = \frac{\left[\left(U\tilde{R_i} - L\tilde{R_i}\right) + \left(M\tilde{R_i} - L\tilde{R_i}\right)\right]}{3} + L\tilde{R_i} \tag{6}$$

where $L\tilde{R_i}$, $M\tilde{R_i}$, $U\tilde{R_i}$ are lower boundary, middle boundary, and upper boundary, respectively.

3. Preparation of the Normalization matrix

After the defuzzification of the fuzzy decision matrix, the defuzzified decision matrix is normalized based on Eq. (7).

Table 2 Risk factors in the collision of two passenger train near the "Haft Khan" station railway

Risk assessment sub-criteria	The type of risk main criteria	Description
X_1	Individual factors	Wrong orders of the traffic control center (Sussman and Raslear 2007; Eftekhari et al. 2018)
X_2		Deactivation of the Automatic train control (ATC) system (Eftekhari et al. 2018; Matsumoto 2006)
X_3		Lack of attention to the red light (Sussman and Raslear 2007; Hani Tabai et al. 2018)
X_4		Lack of the order to exit ATC system (Eftekhari et al. 2018; Matsumoto 2006)
X_5		Radiotelephone's expert system (Braut et al. 2014; Eftekhari et al. 2018)
X_6	Management factors	Absence of an integrated automated control system (Hollnagel 1999; Eftekhari et al. 2018; Patil et al. 2017)
X_7		Lack of a mechanism to identify the weaknesses of the employees' skills (Patil et al. 2017)
X_8	Environmental factors	Defects in the ATC system (Eftekhari et al. 2018; Matsumoto 2006; Hani Tabai et al. 2018)
X_9		Unrealistic nature of most of the ATC warnings (Eftekhari et al. 2018; Matsumoto 2006)
X_{10}		Failure to operate the ATC system efficiently (Eftekhari et al. 2018; Hollnagel 1999)
X_{11}		Lack of the installation of the Balise system (Rodriguez et al. 2016; Eftekhari et al. 2018)
X_{12}		The curvature of the train course (Sadeghi and Akbari 2006; Eftekhari et al. 2018; Sun 2018)
X_{13}		Stop of the front train at the back of the hill (Edkins and Pollock 1997; Eftekhari et al. 2018)
X_{14}		Lack of the visibility of the back trains (Tyrell et al. 2006; Eftekhari et al. 2018)
X_{15}		Difficulty in passing the area (Eftekhari et al. 2018)
X_{16}		Lack of the ground aid (Aher and Tiwari 2018; Eftekhari et al. 2018)
X_{17}	Reaction to event	The capability of a proper reaction to reduce the impact of an event after its occurrence or to prevent casualties, damage, and loss (Aher and Tiwari 2018; Eftekhari et al. 2018)

Table 3 The fuzzy linguistic terms for alternatives in Fuzzy COPRAS (Yazdani et al. 2011)

Linguistic term	Fuzzy rating
Very poor (VP)	(0.0,0.0, 2.5)
Poor (P)	(0.0,2.5,5.0)
Fair (F)	(2.5,5.0,7.5)
Good (G)	(5.0,7.5,10.0)
Very good (VG)	(7.5,10.0,10.0)

Table 4 The fuzzy linguistic terms for the weight of main criteria in Fuzzy DEMATEL (Akyuz and Celik 2015)

Linguistic term	Fuzzy rating
No influence (NO)	(0.0,0.0,0.25)
Very low influence (VL)	(0.0,0.25,0.5)
Low influence (L)	(0.25,0.5,0.75)
High influence (H)	(0.5,0.75,1.0)
Very high influence (VH)	(0.75,1.0,1.0)

$$\bar{X_{ij}} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}; i = 1,2,\ldots,m; \quad j = 1,2,\ldots,n \tag{7}$$

where X_{ij} is the defuzzified element pertaining to the ith row and jth column of the defuzzified decision matrix. After completing each variable, the normalization matrix is constructed as follows:

$$\bar{X} = \begin{bmatrix} \bar{X}_{11} & \bar{X}_{12} & \ldots & \bar{X}_{1n} \\ \bar{X}_{12} & \bar{X}_{22} & \ldots & \bar{X}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \bar{X}_{m1} & \bar{X}_{m1} & \ldots & \bar{X}_{mn} \end{bmatrix} \tag{8}$$

4. Preparation of the weighted normalization fuzzy decision matrix

After normalizing fuzzy decision matrix, the normalization fuzzy decision matrix is weighted using Eq. (9). It is shown as Eq. (10)

$$\hat{X} = \bar{X}_{ij}\bar{w}_j i = 1,2,\ldots,m; \quad j = 1,2,\ldots,n \tag{9}$$

$$\hat{X} = \begin{bmatrix} \hat{X}_{11} & \hat{X}_{12} & \ldots & \hat{X}_{1n} \\ \hat{X}_{21} & \hat{X}_{22} & \ldots & \hat{X}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ X_{m1} & \hat{X}_{m2} & \ldots & \hat{X}_{mn} \end{bmatrix} \tag{10}$$

where $\bar{w}_j$ is defuzzified weight of the jth criterion and is converted to $\bar{w}_j$

5. Calculation of P_i values and R_i values
The P_i and R_i indices are shown for calculating benefit-based indices and cost–benefit indices, respectively. The weighted values of the columns in the weighted normalized fuzzy decision matrix are summed up (benefit-based indices and cost–benefit indices) as Eqs. (11) and (12).

$$P_i = \sum_{j=1}^{k} \hat{X}_{ij} \quad (11)$$

$$R_i = \sum_{j=K+1}^{n} \hat{X}_{ij} \quad (12)$$

In Eqs. (11) and (12), it is assumed that the number of K criteria is benefit-based and the remaining number of nq-K criteria is cost-based.

6. Determination of the relative weight of each alternative

The relative weight of each alternative is determined using Eq. (13)

$$Q_i = P_i + \frac{R_{\min} \sum_{i=1}^{m} R_i}{R_i \sum_{i=1}^{m} \frac{R_{\min}}{R_i}} \quad (13)$$

7. Determination of the optimality criterion $Q_{\max}$
After calculating the relative weight of the matrix, the maximum relative weight of the matrix is obtained and identified as $Q_{\max}$

8. Determination of the utility degree and the priority of the alternatives
The utility degree and the priority of the alternatives are determined using Eq. (14)

$$N_i = \frac{Q_i}{Q_{\max}} 100\%; i = 1, 2, \ldots, m \quad (14)$$

After completing and determining the utility degree and the priority for each alternative in the present study, N_i is assigned to each alternative, and the utility degree is arranged in descending order of degrees (that is from the highest degree to the lowest degree).

3.4 Fuzzy DEMATEL approach

For the first time the DEMATEL technique was proposed by American scientists in 1926. This technique is a method for solving complex problems in decision making. The basis of this method was graph theory which solved problems using simple methods. In another study, Zhang and Deng (2019) applied DEMATEL method as a solver tool of computational complexity of Dempster–Shafer evidence theory in uncertain information. Han and Deng (2018) also proposed an enhanced fuzzy evidential decision-making based on Dempster–Shafer evidence theory and DEMATEL method for identifying critical success factors in accidental and destructive disasters. The findings indicated that the proposed method had an appropriate performance in emergency management.

However, DEMATEL technique cannot make accurate decisions to solve complex problems. In order to correct this defect, the decision making under uncertainty is used in the Fuzzy DEMATEL technique (Wu and Lee 2007; Zhou et al. 2011; Jeng 2015). Fuzzy DEMATEL method utilizes fuzzy linguistic variables and easily makes decisions under environmental uncertainty (Shieh et al. 2010). Other studies have adopted Fuzzy DEMATEL approach as a proper technique in comparison with the other MCDM methods due to cause-effect diagram (Chang et al. 2011; Patil and Kant 2014; Luthra et al. 2016). Yazdani et al. (2020) also developed a fuzzy decision model based on the combined structure of DEMATEL, QFD and fuzzy values in order to eliminate risks in the supply chain related to agricultural production systems. Therefore, the analysis procedures of Fuzzy DEMATEL approach are described in the following steps (Lin 2013; Akyuz and Celik 2015).

1. Establishing fuzzy linguistic criteria

In order to construct a direct-relation matrix, first, the importance of criteria for alternatives is considered. Second, as shown in Table 3, a questionnaire survey method is used to determine the experts' opinions based on the importance and degrees defined for each criterion (Akyuz and Celik 2015; Tsai et al. 2015).

2. Constructing the initial decision matrix
The initial fuzzy direct-relation matrix X^k is constructed by asking the evaluators to determine the fuzzy pair-wise influence relationships between the components in $a\ n \times n$ matrix where k is the number of experts' decision matrix. Accordingly, the direct-relation matrix is established as $X^k = [X_{ij}^k]$ where X is $n \times n$ non-negative matrix, x_{ij} denotes the direct impact of factor i on factor j; and when $i = j$, the diagonal elements $x_{ij} = 0$. For the sake of simplicity, X^k is denoted as

$$x_{ij}^k = (l_{ij}, m_{ij}, u_{ij})$$

$$X^k = \begin{matrix} C_1 \\ C_2 \\ \ldots \\ C_n \end{matrix} \begin{bmatrix} [0,0] & \otimes x_{1n}^k & \ldots & \otimes x_{1n}^k \\ \otimes x_{21}^k & [0,0] & \ldots & \otimes x_{2n}^k \\ \ldots & \ldots & \ldots & \ldots \\ \otimes x_{n1}^k & \otimes x_{n2}^k & \ldots & [0,0] \end{bmatrix} \quad (15)$$

3. Constructing the normalized fuzzy direct-relation matrix:

In order to construct the normalized fuzzy direct-relation matrix "N", which is related to the overall fuzzy direct-relation matrix X^k, Eq. (16) is used as follows:

$$N = \frac{X^k}{\max_{1 \le i \le n}\left(\sum_{j=1}^{n} x_{ij}\right)}, \quad i,j = 1,2,\ldots,n \tag{16}$$

4. Constructing the total-relation matrix T

In order to determine the total-relation matrix T, where $n \times n$ identity matrix is denoted with I. Upper and lower values are estimated separately using Eq. (17):

$$T = \lim_{K\to\infty}\left(N + N^2 + \cdots + N^k\right) = N(I-N)^{-1} \tag{17}$$

where N is the normalized fuzzy direct-relation matrix

5. Determining row (D_i) and column (R_j) sums

In order to calculate the sums of row (D_i), and column (R_j) for each row i, and column j in the total-relation matrix (T), Eqs. (18), (19) and (20) are used as follows:

$$T = \left[t_{ij}\right]_{n\times n} \quad (i,j = 1,2,\ldots,n) \tag{18}$$

$$\tilde{D}_i = \sum_{1\le j\le n}^{n} t_{ij} \quad \forall i \tag{19}$$

$$\tilde{R}_j = \sum_{1\le i\le n}^{n} t_{ij} \quad \forall \mathrm{j} \tag{20}$$

6. Determining the prominence and relation values.

In this step, a cause–effect diagram is drawn. This diagram consists of two axes including horizontal axis ($\tilde{D}_i + \tilde{R}_j$) which is drawn by adding R to D and the vertical axis ($\tilde{D}_i - \tilde{R}_j$) which is drawn by subtracting $\tilde{R}_j$ from $\tilde{D}_i$.

The horizontal axis ($\tilde{D}_i + \tilde{R}_j$) indicates the prominence based on the importance degree of sub-criteria used in the study. On the other hand, the vertical axis ($\tilde{D}_i - \tilde{R}_j$) represents the relation on the basis of influence. If the relation is negative, the sub-criteria will be classified as the effect group which is influenced by other criteria. Nonetheless, if the relation is positive, the sub-criteria will be classified as the cause group which has a significant impact on other sub-criteria.

7. Defuzzification of ($\tilde{D}_i + \tilde{R}_j$) and ($\tilde{D}_i - \tilde{R}_j$) values

Defuzzification of ($\tilde{D}_i + \tilde{R}_j$) and ($\tilde{D}_i - \tilde{R}_j$) is carried out via ($\tilde{D}_i - \tilde{R}_j$) = ($S_1$, S_2, S_3); ($\tilde{D}_i + \tilde{R}_j$) = ($U_1$, U_2, U_3), and Eqs. (21) and (22):

$$\left(\tilde{D}_i - \tilde{R}_j\right)_{\mathrm{def}} = \frac{1}{4}(S_1 + 2S_2 + S_3) \tag{21}$$

$$\left(\tilde{D}_i + \tilde{R}_j\right)_{\mathrm{def}} = \frac{1}{4}(U_1 + 2U_2 + U_3) \tag{22}$$

where S_1, S_2, and S_3 are lower boundary, medium boundary, and upper boundary of matrix ($\tilde{D}_i - \tilde{R}_j$), respectively. U_1, U_2, and U_3 are lower boundary, medium boundary, and upper boundary of matrix ($\tilde{D}_i + \tilde{R}_j$), respectively.

8. Calculating the importance weights of the risk sub-criteria.

In order to determine the importance weights of the risk sub-criteria, Eqs. (23) and (24) are used (Lin 2013; Akyuz and Celik 2015)

$$W_j = \sqrt{\left(\tilde{D}_i + \tilde{R}_j\right)_{\mathrm{def}}^2 + \left(\tilde{D}_i - \tilde{R}_j\right)_{\mathrm{def}}^2} \tag{23}$$

$$\omega_j = \frac{W_j}{\sum_{j=1}^{n} W_j} \quad (j = 1,2,\ldots,n) \tag{24}$$

where W_j is the importance weight for each sub-criterion. $\sum_{j=1}^{n} W_j$ is the sum of the importance weights for sub-criteria.

9. Prioritizing the risk sub-criteria based on obtained weights

The risk sub-criteria for the collision of two passenger trains are ranked in the order of values (that is from the highest values to the lowest values) of the obtained weights.

According to the proposed method, cause-effect factors are identified, and the relationship between these factors is determined through the examination of the impact of severe degree on each sub-criterion.

4 Analysis and results

In this section, sample data description is provided, and field observation and survey results are shown using Fuzzy COPRAS and Fuzzy DEMATEL methods in order to assess and prioritize critical risk factors in the collision of two passenger trains in ''Haft Khan'' station.

Table 5 Background information and basic statistics for decision makers

Demographic variables	No	Percentage (%)
Gender		
Male	98	63.63
Female	56	36.37
Age		
25–30	49	31.82
31–40	65	42.21
41–50	25	16.23
More than 50	15	9.74
Education		
Bachelor	79	51.30
Master	53	34.42
PhD	22	14.28
Work experience		
1–5	30	19.48
6–10	64	41.55
11–15	44	28.57
More than 15 years	16	10.40

4.1 Sample data description

In order to conduct the questionnaire survey, the researchers invited the experts based on two main criteria. To be more specific, first, the experts had to have considerable work experience of the issues of railway industry, relevant standards, and theoretical studies. Second, they had to be involved in the safety and risk management of train collisions or have in-depth knowledge of the safety and risk factors with the help of research. Therefore, 154 experts were invited to fill out the questionnaires on the basis of demographic characteristics which are shown in Table 5. The questionnaires were distributed in most of the railway consultancies and among the government employees of Iranian railways. A total of 135 completed survey questionnaires was returned in June 2019. These questionnaires showed that the response rate was 87.66%. Among these 135 questionnaires, 19 questionnaires were invalid due to blank spaces, and illegible, invalid, or multiple answers. Based on the sample size of 55, the 116 returned and valid questionnaires were deemed to be adequate and reliable for the purposes of this study.

4.2 Field observation and survey results

Questionnaire data were linked to some observation data. The observation data were collected by visiting official sites of Iranian railway organization and examining reliable reported news about the relevant field (Salamatnews 2016; Asgari 2016; Farsnews agency 2016; ISNA 2016). More specifically, these data were gathered by trying to answer some questions:'' What is the main cause of the collision of two passenger trains in Haft-Khan station?''. ''What are the most critical risk factors in the collision of two passenger trains'. Based on the results, about 80% of the responses indicated that the risk factors in the collision of two passenger trains in ''Haft-Khan'' station were: (a) the lack of attention to the red light; (b) the curvature of the train course which led to mechanical failure; and (c) the cold weather which forced the front train to stop at the back of the hill. The first factor has been called the individual factor. On the other hand, the second and the third factors have been called environmental factors. Figures 3a–e shows these results.

4.3 Fuzzy COPRAS

In order to identify risk factors, first, experts (as decision makers) were invited to evaluate alternatives (sub-criteria) and the weights of criteria with respect to each criterion based on the linguistic variables presented in Tables 3 and 4. Next, as shown in Table 6, the aggregated fuzzy decision matrix was prepared using Eq. (4).

The fuzzy weight was obtained by converting linguistic variables into triangular fuzzy numbers based on Eqs. (5) and (6). As shown in Table 6, defuzzification of the fuzzy decision matrix was carried out using the crisp weights calculated by Eq. (6).

In order to calculate the weighted decision for the existing alternatives (sub-criteria), Eqs. (7) to (10) were used. The above-mentioned equations multiplied the weights of criteria in Eq. (9) using the normalized decision matrix. These results are shown in Table 7.

Table 7 shows that C_1, C_2, and C_3 are the costs of the main criteria. On the other hand, based on this table, C_4 is the benefit of the main criteria. Finally, summing up the weighted values of columns of the weighted normalization fuzzy decision matrix was carried out using Eqs. (11) and (12). The relative weight of each alternative was used for all of the seventeen alternatives (sub-criteria) in Eq. (13). Moreover, the utility degree of each alternative was determined using Eq. (14). These results are shown in Table 8. According to N_i (%) for risk sub-criteria, the risk ranking in descending order is X_3, X_4, X_7, X_{14}, X_1, X_{10}, X_5, X_{12}, X_{17}, X_{16}, X_8, X_{15}, X_2, X_{11}, X_{13}, X_6, and X_9. Therefore, the risk factor with the highest rank is X_3 (Lack of attention to the red light), and the risk factor with the lowest rank is X_9 (Unrealistic nature of most ATC warnings) (Table 9).

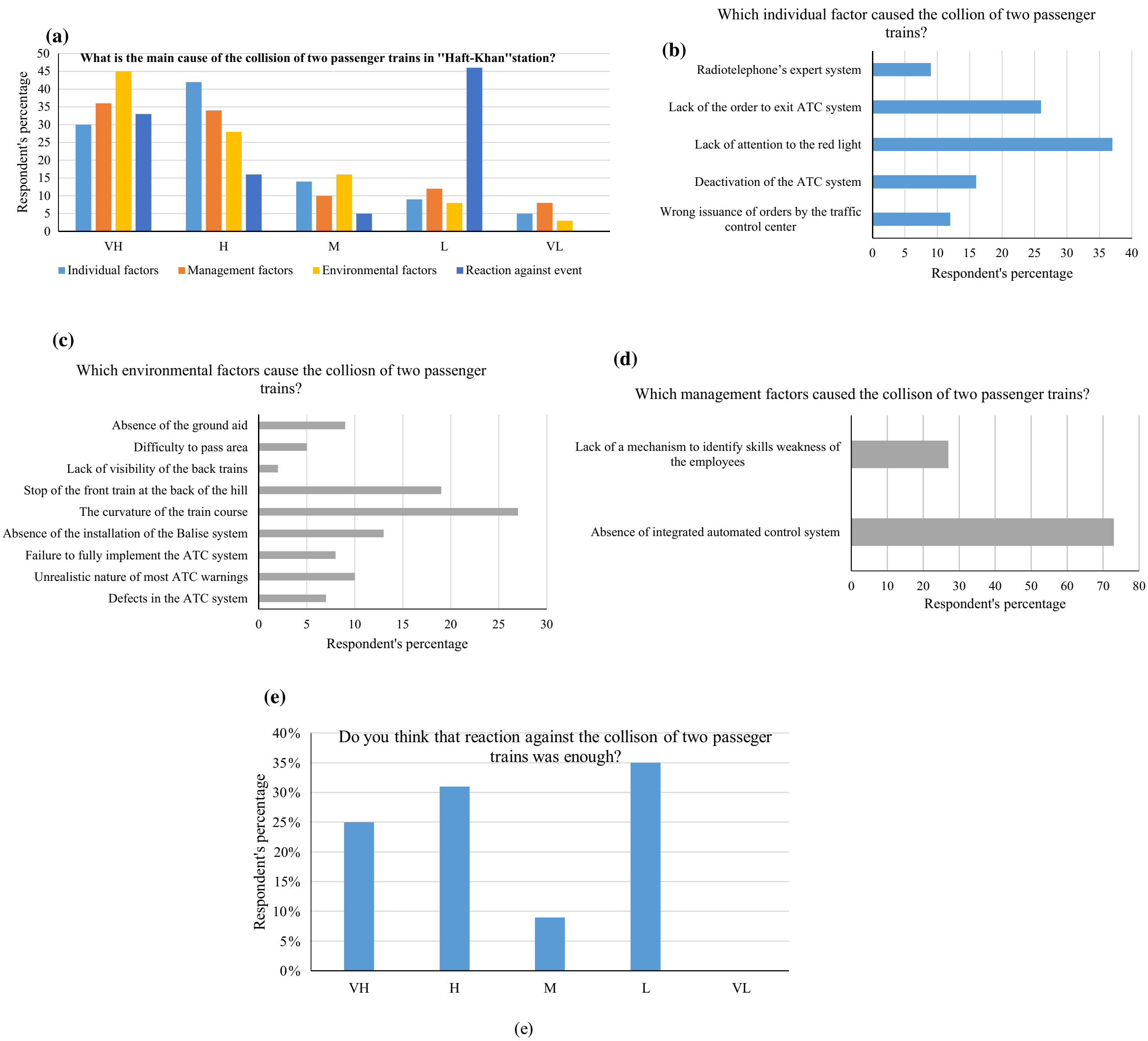

Fig. 3 Survey results of **a** the most effective factors in the collision of two passenger trains, **b** individual factors, **c** environmental factors, **d** management factors, **e** reaction to the event by experts

Table 6 Railway criteria along with their fuzzy weights, and defuzzified weights

Criteria	Sub-criteria	Type of sub-criterion	Fuzzy weight of sub-criterion			Defuzzified weight of sub-criterion
Railway criteria, their fuzzy weights, and defuzzified weights						
Individual criterion (C_1)	X_1, X_2, X_3, X_4, X_5	Cost	0.266	0.422	0.623	0.437
Managerial criterion (C_2)	X_6, X_7	Cost	0.565	0.762	0.898	0.742
Environmental criterion (C_3)	X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}	Cost	0.520	0.675	0.810	0.668
Detectability (C_4)	X_{17}	Benefit	0.377	0.561	0.692	0.543

Table 7 Fuzzy decision matrix

	C_1	C_2	C_3	C_4
X_1	(5.5 6.2 7.7)	(6.7 7.3 8.1)	(1.5 2.3 3.1)	(4.7 6.6 7.8)
X_2	(3.3 4.9 6.1)	(7.8 8.2 9.2)	(3.7 5.8 6.7)	(5.9 7.2 8.9)
X_3	(2.1 3.4 4.3)	(3.3 4.1 5.5)	(1.7 2.8 3.4)	(4.9 6.8 8.3)
X_4	(1.5 2.9 4.5)	(2.8 4.3 6.2)	(1.3 2.7 4.3)	(5.6 6.3 7.8)
X_5	(2.3 4.2 6.0)	(4.7 6.1 7.5)	(5.6 7.1 8.3)	(6.6 8.7 9.3)
X_6	(3.4 5.5 6.4)	(6.7 8.2 9.5)	(4.8 6.0 7.4)	(1.3 2.7 4.6)
X_7	(1.6 3.3 4.7)	(4.9 5.7 6.8)	(3.0 3.8 4.1)	(2.8 3.7 5.1)
X_8	(2.6 3.8 5.1)	(5.6 6.7 7.9)	(6.3 7.2 8.1)	(5.9 6.7 7.9)
X_9	(5.3 7.6 9.2)	(2.8 4.5 6.4)	(1.4 2.2 3.3)	(2.9 4.5 6.2)
X_{10}	(1.9 2.4 3.1)	(4 5.1 6.4)	(7.0 8.3 9.6)	(6.7 7.8 9.7)
X_{11}	(1.1 2.3 3.4)	(7.2 8.6 9.8)	(5.0 6.3 7.9)	(3.7 4.6 6.0)
X_{12}	(2.3 3.6 4.1)	(1.7 2.5 3.8)	(7.0 8.6 9.9)	(2.6 3.8 4.7)
X_{13}	(6.9 7.8 8.8)	(3.9 4.7 6.1)	(5.8 6.7 8.2)	(4.4 5.8 6.7)
X_{14}	(4.5 6.2 7.1)	(4.6 6.0 7.5)	(1.6 2.3 3.7)	(3.0 4.1 5.9)
X_{15}	(1.9 3.3 4.6)	(3.0 4.1 5.9)	(6.8 7.9 9.3)	(6.5 7.9 9.3)
X_{16}	(3.6 4.9 6.2)	(7.0 8.5 9.7)	(2.9 4.5 6.1)	(5.7 6.8 8.2)
X_{17}	(4.4 6.1 7.9)	(6.7 8.1 9.9)	(3.7 4.9 6.6)	(7.4 8.5 9.7)
$\sum \tilde{R}_i = \left(L\tilde{R}_i, M\tilde{R}_i, U\tilde{R}_i\right)$	(54.2 78.4 99.2)	(83.4 102.7 126.2)	(69.1 89.4 110)	(80.6 102.5 126.2)

Table 8 The weighted normalized decision matrix

	C_1	C_2	C_3	C_4
X_1	0.037	0.053	0.017	0.034
X_2	0.027	0.060	0.040	0.037
X_3	0.018	0.031	0.020	0.035
X_4	0.017	0.032	0.021	0.035
X_5	0.024	0.043	0.052	0.043
X_6	0.029	0.058	0.045	0.015
X_7	0.018	0.041	0.027	0.020
X_8	0.022	0.048	0.054	0.036
X_9	0.095	0.033	0.026	0.024
X_{10}	0.014	0.037	0.062	0.042
X_{11}	0.013	0.061	0.048	0.025
X_{12}	0.019	0.019	0.063	0.019
X_{13}	0.044	0.035	0.051	0.030
X_{14}	0.034	0.043	0.019	0.023
X_{15}	0.042	0.031	0.060	0.042
X_{16}	0.028	0.060	0. 034	0.036
X_{17}	0.035	0.059	0.038	0.045

Table 9 Results of fuzzy COPRAS

	P_i	R_i	Q_I	N_i (%)	Rank
X_1	0.034	0.107	0.150	6.05	5
X_2	0.037	0.127	0.134	5.408	13
X_3	0.035	0.069	0.214	8.64	1
X_4	0.035	0.07	0.212	8.56	2
X_5	0.043	0.119	0.147	5.93	7
X_6	0.015	0.132	0.109	4.40	16
X_7	0.020	0.086	0.164	6.62	3
X_8	0.036	0.124	0.136	5.49	11
X_9	0.024	0.154	0.104	4.20	17
X_{10}	0.042	0.113	0.149	6.01	6
X_{11}	0.025	0.122	0.126	5.08	14
X_{12}	0.019	0.101	0.142	5.73	8
X_{13}	0.030	0.130	0.125	5.04	15
X_{14}	0.023	0.096	0.152	6.13	4
X_{15}	0.042	0.133	0.135	5.45	12
X_{16}	0.036	0.122	0.137	5.52	10
X_{17}	0.045	0.132	0.139	5.61	9

4.4 Fuzzy DEMATEL approach

The fuzzy DEMATEL approach was adopted to identify casual and influential factors in the collision of two passenger trains. The results of this method are shown in Tables 10, 11, 12 and 13.

The initial direct-fuzzy matrix is illustrated in Table 10. After gaining established initial direct-fuzzy matrix, normalized direct-relation fuzzy matrix was obtained using Eqs. 15 and 16. The normalized initial direct-relation fuzzy matrix was determined based on Table 11. Furthermore, the total-relation fuzzy matrix was determined using

Table 10 Linguistic assessment of the evaluators' opinion (average)

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}
X_1	NO	H	H	L	NO	VH	VL	VH	VH	H	NO	NO	VL	L	NO	NO	L
X_2	H	NO	H	H	VL	VH	L	H	VH	VH	NO	NO	H	L	VL	NO	H
X_3	VH	H	NO	VL	L	H	VL	H	H	VH	NO	NO	H	VL	L	NO	VL
X_4	VL	L	VL	NO	VL	H	H	L	H	H	NO	NO	VH	H	VL	NO	H
X_5	L	H	VH	H	NO	VL	L	H	H	VH	NO	NO	H	H	L	NO	H
X_6	H	VH	H	VH	H	NO	VL	H	VH	VH	NO	NO	H	L	VL	L	VH
X_7	L	VL	VH	H	L	VL	NO	L	L	VL	NO	NO	H	VH	L	H	H
X_8	H	VH	NO	VH	H	NO	NO	NO	VL	NO	NO	NO	H	H	L	L	H
X_9	VH	VH	H	H	VH	H	VH	H	NO	VH	NO	NO	VH	VL	L	VL	H
X_{10}	H	VH	VL	H	L	H	NO	H	NO	NO	NO	NO	L	VL	VL	L	VH
X_{11}	VL	L	VL	NO	NO	NO	NO	NO	NO	NO	NO	H	L	L	VH	NO	NO
X_{12}	L	VL	L	NO	NO	NO	NO	NO	NO	NO	H	NO	VH	VH	H	VH	VH
X_{13}	H	VH	VL	H	VH	VH	L	VH	H	VH	L	L	NO	H	H	L	H
X_{14}	L	L	H	VH	H	L	L	H	VH	VH	L	L	H	NO	VH	H	H
X_{15}	NO	NO	NO	L	NO	L	L	L	NO	VL	H	VH	H	H	NO	VH	H
X_{16}	L	VL	L	NO	NO	NO	L	L	NO	L	VH	H	L	VH	H	NO	VH
X_{17}	VH	VH	L	H	H	H	VH	VH	H	H	L	VL	H	VH	NO	NO	NO

Table 11 Normalized initial direct-relation fuzzy matrix

	*X*1			*X*2			*X*3			*X*4			*X*5		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
*X*1	0.00	0.00	0.02	0.06	0.06	0.07	0.06	0.06	0.07	0.03	0.04	0.05	0.00	0.00	0.02
*X*2	0.06	0.04	0.07	0.00	0.00	0.02	0.06	0.06	0.07	0.06	0.06	0.07	0.00	0.02	0.03
*X*3	0.10	0.09	0.07	0.06	0.06	0.07	0.00	0.00	0.02	0.00	0.02	0.03	0.03	0.04	0.05
*X*4	0.00	0.02	0.03	0.03	0.04	0.05	0.00	0.02	0.03	0.00	0.00	0.02	0.00	0.02	0.03
*X*5	0.03	0.04	0.05	0.06	0.06	0.07	0.10	0.09	0.07	0.06	0.06	0.07	0.00	0.00	0.02
*X*6	0.06	0.06	0.07	0.10	0.09	0.07	0.06	0.06	0.07	0.10	0.09	0.07	0.06	0.06	0.07
*X*7	0.03	0.04	0.05	0.00	0.02	0.03	0.10	0.09	0.07	0.06	0.06	0.07	0.03	0.04	0.05
*X*8	0.06	0.06	0.07	0.10	0.09	0.07	0.00	0.00	0.02	0.10	0.09	0.07	0.06	0.06	0.07
*X*9	0.10	0.09	0.07	0.10	0.09	0.07	0.06	0.06	0.07	0.06	0.06	0.07	0.10	0.09	0.07
*X*10	0.06	0.06	0.07	0.10	0.09	0.07	0.00	0.02	0.07	0.06	0.06	0.07	0.03	0.04	0.05
*X*11	0.00	0.02	0.03	0.03	0.04	0.05	0.00	0.02	0.03	0.00	0.00	0.02	0.00	0.00	0.02
*X*12	0.03	0.04	0.05	0.00	0.02	0.03	0.03	0.04	0.05	0.00	0.00	0.02	0.00	0.00	0.02
*X*13	0.06	0.06	0.07	0.10	0.09	0.07	0.00	0.02	0.03	0.06	0.06	0.07	0.10	0.09	0.07
*X*14	0.03	0.04	0.05	0.03	0.04	0.05	0.06	0.06	0.07	0.10	0.09	0.07	0.06	0.06	0.07
*X*15	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.03	0.04	0.05	0.00	0.00	0.02
*X*16	0.03	0.04	0.05	0.00	0.02	0.03	0.03	0.04	0.05	0.00	0.00	0.02	0.00	0.00	0.02
*X*17	0.10	0.09	0.07	0.10	0.09	0.07	0.03	0.04	0.05	0.06	0.06	0.07	0.06	0.06	0.07

	*X*6			*X*7			*X*8			*X*9		
	L	M	U	L	M	U	L	M	U	L	M	U
*X*1	0.10	0.09	0.07	0.00	0.02	0.03	0.10	0.09	0.07	0.10	0.09	0.07
*X*2	0.10	0.09	0.07	0.03	0.04	0.05	0.06	0.06	0.07	0.10	0.09	0.07
*X*3	0.06	0.06	0.07	0.00	0.02	0.03	0.06	0.06	0.07	0.06	0.06	0.07
*X*4	0.06	0.06	0.07	0.06	0.06	0.07	0.03	0.04	0.05	0.06	0.06	0.07
*X*5	0.00	0.02	0.03	0.03	0.04	0.05	0.06	0.06	0.07	0.06	0.06	0.07
*X*6	0.00	0.00	0.02	0.00	0.02	0.03	0.06	0.06	0.07	0.10	0.09	0.07

Table 11 (continued)

	*X*6			*X*7			*X*8			*X*9		
	L	M	U	L	M	U	L	M	U	L	M	U
*X*7	0.00	0.02	0.03	0.00	0.00	0.02	0.03	0.04	0.05	0.03	0.04	0.05
*X*8	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.02	0.03
*X*9	0.06	0.06	0.07	0.10	0.09	0.07	0.06	0.06	0.07	0.00	0.00	0.02
*X*10	0.06	0.06	0.07	0.00	0.00	0.02	0.06	0.06	0.07	0.00	0.00	0.02
*X*11	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02
*X*12	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02
*X*13	0.10	0.09	0.07	0.03	0.04	0.05	0.10	0.09	0.07	0.06	0.06	0.07
*X*14	0.03	0.04	0.05	0.03	0.04	0.05	0.06	0.06	0.07	0.10	0.09	0.07
*X*15	0.00	0.04	0.05	0.00	0.04	0.05	0.00	0.04	0.05	0.00	0.00	0.02
*X*16	0.00	0.00	0.02	0.03	0.04	0.05	0.03	0.04	0.05	0.00	0.00	0.02
*X*17	0.06	0.06	0.07	0.10	0.09	0.07	0.10	0.09	0.07	0.06	0.06	0.07

	*X*10			*X*11			*X*12			*X*13		
	L	M	U	L	M	U	L	M	U	L	M	U
*X*1	0.06	0.06	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.02	0.03
*X*2	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07
*X*3	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07
*X*4	0.06	0.06	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.10	0.09	0.07
*X*5	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07
*X*6	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07
*X*7	0.00	0.02	0.03	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07
*X*8	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07
*X*9	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.10	0.09	0.07
*X*10	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.03	0.04	0.05
*X*11	0.00	0.00	0.02	0.00	0.00	0.02	0.06	0.06	0.07	0.03	0.04	0.05
*X*12	0.00	0.00	0.02	0.06	0.06	0.07	0.00	0.00	0.02	0.10	0.09	0.07
*X*13	0.10	0.09	0.07	0.03	0.04	0.05	0.03	0.04	0.05	0.00	0.00	0.02
*X*14	0.10	0.09	0.07	0.03	0.04	0.05	0.03	0.04	0.05	0.06	0.06	0.07
*X*15	0.00	0.02	0.03	0.06	0.06	0.07	0.10	0.09	0.07	0.06	0.06	0.07
*X*16	0.03	0.04	0.05	0.10	0.09	0.07	0.06	0.06	0.07	0.03	0.04	0.05
*X*17	0.06	0.06	0.07	0.03	0.04	0.05	0.00	0.02	0.03	0.06	0.06	0.07

	*X*14			*X*15			*X*16			*X*17		
	L	M	U	L	M	U	L	M	U	L	M	U
*X*1	0.03	0.04	0.05	0.00	0.00	0.02	0.00	0.00	0.02	0.03	0.04	0.05
*X*2	0.03	0.04	0.05	0.00	0.02	0.03	0.00	0.00	0.02	0.06	0.06	0.07
*X*3	0.00	0.02	0.03	0.03	0.04	0.05	0.00	0.00	0.02	0.00	0.02	0.03
*X*4	0.06	0.06	0.07	0.00	0.02	0.03	0.00	0.00	0.02	0.06	0.06	0.07
*X*5	0.06	0.06	0.07	0.03	0.04	0.05	0.00	0.00	0.02	0.06	0.06	0.07
*X*6	0.03	0.04	0.05	0.00	0.02	0.03	0.03	0.04	0.05	0.10	0.09	0.07
*X*7	0.10	0.09	0.07	0.03	0.04	0.05	0.06	0.06	0.07	0.06	0.06	0.07
*X*8	0.06	0.06	0.07	0.03	0.04	0.05	0.03	0.04	0.05	0.06	0.06	0.07
*X*9	0.00	0.02	0.03	0.03	0.04	0.05	0.00	0.02	0.03	0.06	0.06	0.07
*X*10	0.00	0.02	0.03	0.00	0.02	0.03	0.03	0.04	0.05	0.10	0.09	0.07
*X*11	0.03	0.04	0.05	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02
*X*12	0.10	0.09	0.07	0.06	0.06	0.07	0.10	0.09	0.07	0.10	0.09	0.07
*X*13	0.06	0.06	0.07	0.06	0.06	0.07	0.03	0.04	0.05	0.06	0.06	0.07

Table 11 (continued)

	*X*14			*X*15			*X*16			*X*17		
	L	M	U	L	M	U	L	M	U	L	M	U
*X*14	0.00	0.00	0.02	0.10	0.06	0.07	0.06	0.06	0.07	0.06	0.06	0.07
*X*15	0.06	0.06	0.07	0.00	0.00	0.02	0.10	0.09	0.07	0.06	0.06	0.07
*X*16	0.10	0.09	0.07	0.06	0.06	0.07	0.00	0.00	0.02	0.10	0.09	0.07
*X*17	0.10	0.09	0.07	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.02

Table 12 Total-relation fuzzy matrix

	*X*1			*X*2			*X*3			*X*4			*X*5		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
*X*1	0.12	0.13	0.25	0.20	0.21	0.30	0.14	0.17	0.28	0.16	0.18	0.28	0.09	0.11	0.21
*X*2	0.21	0.20	0.33	0.18	0.18	0.29	0.16	0.19	0.31	0.22	0.23	0.33	0.11	0.15	0.26
*X*3	0.20	0.22	0.31	0.20	0.22	0.31	0.08	0.11	0.24	0.12	0.17	0.28	0.11	0.15	0.26
*X*4	0.12	0.16	0.28	0.17	0.20	0.30	0.08	0.13	0.26	0.13	0.15	0.27	0.10	0.14	0.24
*X*5	0.17	0.20	0.32	0.23	0.24	0.34	0.19	0.21	0.32	0.21	0.23	0.34	0.11	0.13	0.25
*X*6	0.23	0.24	0.35	0.29	0.29	0.35	0.18	0.21	0.32	0.27	0.27	0.35	0.19	0.21	0.30
*X*7	0.15	0.18	0.30	0.13	0.18	0.29	0.17	0.20	0.30	0.18	0.21	0.32	0.12	0.16	0.26
*X*8	0.17	0.18	0.29	0.22	0.22	0.30	0.08	0.10	0.23	0.21	0.21	0.30	0.14	0.16	0.26
*X*9	0.27	0.26	0.35	0.30	0.29	0.35	0.19	0.21	0.33	0.25	0.26	0.35	0.22	0.23	0.30
*X*10	0.17	0.19	0.31	0.22	0.23	0.31	0.08	0.12	0.29	0.18	0.20	0.31	0.11	0.14	0.25
*X*11	0.04	0.08	0.19	0.07	0.10	0.21	0.03	0.07	0.18	0.04	0.06	0.18	0.03	0.04	0.15
*X*12	0.13	0.15	0.25	0.11	0.14	0.24	0.10	0.13	0.24	0.10	0.11	0.22	0.08	0.09	0.19
*X*13	0.24	0.25	0.37	0.30	0.30	0.37	0.13	0.18	0.32	0.26	0.27	0.37	0.22	0.23	0.32
*X*14	0.20	0.23	0.35	0.23	0.25	0.35	0.18	0.21	0.35	0.27	0.27	0.37	0.19	0.21	0.32
*X*15	0.08	0.12	0.24	0.09	0.13	0.24	0.05	0.09	0.22	0.11	0.16	0.27	0.06	0.09	0.21
*X*16	0.13	0.16	0.28	0.11	0.15	0.26	0.10	0.14	0.26	0.10	0.13	0.24	0.07	0.09	0.21
*X*17	0.26	0.26	0.35	0.30	0.29	0.36	0.16	0.19	0.32	0.25	0.26	0.36	0.19	0.21	0.31

	*X*6			*X*7			*X*8			*X*9		
	L	M	U	L	M	U	L	M	U	L	M	U
*X*1	0.20	0.20	0.28	0.06	0.11	0.21	0.22	0.23	0.31	0.20	0.21	0.31
*X*2	0.23	0.23	0.31	0.11	0.15	0.26	0.23	0.24	0.35	0.24	0.23	0.35
*X*3	0.17	0.19	0.29	0.06	0.11	0.22	0.19	0.22	0.32	0.17	0.19	0.32
*X*4	0.17	0.19	0.29	0.13	0.16	0.26	0.16	0.20	0.31	0.17	0.19	0.31
*X*5	0.13	0.17	0.28	0.11	0.15	0.26	0.22	0.24	0.35	0.20	0.21	0.35
*X*6	0.16	0.17	0.27	0.10	0.15	0.25	0.25	0.26	0.36	0.26	0.25	0.36
*X*7	0.10	0.16	0.27	0.07	0.10	0.22	0.16	0.20	0.32	0.15	0.18	0.32
*X*8	0.11	0.12	0.23	0.07	0.09	0.20	0.13	0.14	0.26	0.12	0.14	0.26
*X*9	0.23	0.24	0.33	0.19	0.21	0.29	0.26	0.27	0.37	0.17	0.18	0.37
*X*10	0.16	0.18	0.29	0.06	0.09	0.21	0.18	0.20	0.32	0.11	0.13	0.32
*X*11	0.03	0.06	0.16	0.02	0.04	0.14	0.04	0.07	0.18	0.04	0.05	0.18
*X*12	0.09	0.10	0.20	0.06	0.08	0.18	0.11	0.13	0.23	0.10	0.10	0.23
*X*13	0.25	0.26	0.34	0.13	0.18	0.29	0.29	0.30	0.39	0.24	0.24	0.39
*X*14	0.18	0.21	0.33	0.13	0.17	0.29	0.24	0.27	0.38	0.25	0.25	0.38
*X*15	0.07	0.14	0.25	0.05	0.12	0.23	0.09	0.16	0.28	0.07	0.10	0.28
*X*16	0.08	0.11	0.22	0.09	0.12	0.23	0.14	0.17	0.29	0.09	0.11	0.29

Table 12 (continued)

	X6			*X7*			*X8*			*X9*		
	L	M	U	L	M	U	L	M	U	L	M	U
X17	0.22	0.23	0.33	0.19	0.21	0.29	0.29	0.28	0.37	0.24	0.24	0.37

	X10			*X11*			*X12*			*X13*		
	L	M	U	L	M	U	L	M	U	L	M	U
X1	0.20	0.21	0.28	0.02	0.03	0.29	0.02	0.03	0.14	0.13	0.17	0.14
X2	0.27	0.26	0.31	0.03	0.05	0.33	0.02	0.04	0.17	0.22	0.24	0.16
X3	0.22	0.23	0.29	0.02	0.04	0.30	0.02	0.04	0.15	0.17	0.21	0.15
X4	0.20	0.22	0.29	0.03	0.04	0.31	0.02	0.04	0.16	0.22	0.23	0.15
X5	0.26	0.26	0.31	0.03	0.05	0.33	0.03	0.04	0.17	0.21	0.24	0.16
X6	0.29	0.28	0.32	0.04	0.06	0.34	0.03	0.05	0.17	0.24	0.26	0.17
X7	0.14	0.18	0.28	0.04	0.05	0.28	0.03	0.05	0.16	0.19	0.22	0.16
X8	0.14	0.14	0.25	0.03	0.04	0.24	0.03	0.04	0.15	0.18	0.20	0.14
X9	0.30	0.29	0.28	0.04	0.06	0.34	0.03	0.05	0.18	0.28	0.29	0.17
X10	0.13	0.14	0.24	0.03	0.04	0.26	0.02	0.04	0.15	0.14	0.18	0.15
X11	0.04	0.06	0.16	0.02	0.03	0.17	0.09	0.09	0.11	0.08	0.11	0.16
X12	0.12	0.12	0.20	0.11	0.11	0.22	0.04	0.05	0.19	0.20	0.21	0.14
X13	0.30	0.30	0.34	0.08	0.11	0.36	0.07	0.10	0.22	0.20	0.22	0.22
X14	0.29	0.28	0.34	0.08	0.11	0.36	0.08	0.10	0.23	0.25	0.27	0.22
X15	0.09	0.14	0.22	0.11	0.12	0.25	0.13	0.13	0.20	0.16	0.19	0.20
X16	0.14	0.17	0.22	0.13	0.13	0.27	0.10	0.11	0.20	0.14	0.18	0.20
X17	0.27	0.27	0.33	0.07	0.09	0.35	0.03	0.07	0.21	0.25	0.27	0.19

	X14			*X15*			*X16*			*X17*		
	L	M	U	L	M	U	L	M	U	L	M	U
X1	0.12	0.16	0.29	0.05	0.08	0.28	0.04	0.07	0.20	0.16	0.19	0.30
X2	0.15	0.19	0.36	0.06	0.12	0.31	0.06	0.08	0.25	0.23	0.24	0.36
X3	0.09	0.15	0.33	0.08	0.13	0.28	0.04	0.07	0.25	0.13	0.18	0.30
X4	0.16	0.20	0.34	0.06	0.11	0.31	0.05	0.08	0.24	0.19	0.22	0.34
X5	0.18	0.21	0.36	0.10	0.14	0.34	0.06	0.08	0.27	0.22	0.24	0.36
X6	0.17	0.22	0.37	0.07	0.14	0.33	0.09	0.13	0.26	0.28	0.28	0.37
X7	0.20	0.22	0.35	0.10	0.14	0.32	0.11	0.14	0.26	0.19	0.22	0.34
X8	0.16	0.19	0.32	0.09	0.12	0.30	0.08	0.10	0.24	0.19	0.20	0.32
X9	0.15	0.20	0.38	0.11	0.16	0.32	0.07	0.12	0.28	0.26	0.27	0.38
X10	0.10	0.15	0.32	0.04	0.10	0.28	0.07	0.10	0.23	0.21	0.23	0.33
X11	0.08	0.10	0.23	0.12	0.13	0.21	0.03	0.04	0.20	0.05	0.07	0.19
X12	0.20	0.20	0.29	0.13	0.14	0.27	0.15	0.15	0.24	0.21	0.21	0.29
X13	0.22	0.26	0.35	0.15	0.19	0.37	0.11	0.15	0.32	0.27	0.29	0.40
X14	0.15	0.19	0.40	0.18	0.19	0.32	0.14	0.16	0.32	0.26	0.27	0.40
X15	0.15	0.19	0.32	0.06	0.09	0.30	0.14	0.15	0.21	0.16	0.20	0.31
X16	0.19	0.21	0.30	0.13	0.15	0.30	0.06	0.07	0.26	0.21	0.22	0.31
X17	0.24	0.26	0.38	0.09	0.12	0.35	0.07	0.10	0.25	0.20	0.21	0.33

Eqs. (17) and (18). The results of the total-relation fuzzy matrix are shown in Table 12. The total sum of rows and columns in the obtained fuzzy total-relation matrix was determined using Eqs. 19 and 20, respectively. Table 13 illustrates defuzzified weights and calculates the importance weights using Eqs. 21–24.

Table 13 Prominence and relation axis for the causal diagram

Sub-criteria	$(\tilde{D}_i + \tilde{R}_j)$	$(\tilde{D}_i - \tilde{R}_j)$	W_i	Rank
X_1	6.44	− 0.77	0.0639	10
X_2	7.34	− 0.53	0.0726	4
X_3	5.99	− 0.10	0.0591	12
X_4	6.74	− 0.73	0.0669	9
X_5	6.31	0.55	0.0624	11
X_6	7.12	0.49	0.0703	6
X_7	5.67	0.59	0.0562	13
X_8	6.73	− 1.14	0.0673	7
X_9	7.31	0.53	0.0723	5
X_{10}	6.72	− 1.04	0.0671	8
X_{11}	3.11	0.01	0.0307	17
X_{12}	4.03	1.13	0.0412	16
X_{13}	8.26	0.11	0.0814	1
X_{14}	7.66	0.42	0.0757	3
X_{15}	5.22	0.02	0.0515	14
X_{16}	4.91	0.65	0.0488	15
X_{17}	8.07	− 0.19	0.0796	2

The cause and effect factors were identified based on the results which were obtained at the sixth stage of Fuzzy DEMATEL method. Figure 4 shows these results. The given sub-criteria were classified as cause (X_5, X_6, X_7, X_9, X_{11}, X_{12}, X_{13}, X_{14}, X_{15} and X_{16}) and effect (X_1, X_2, X_3, X_4, X_8, X_{10}, and X_{17}) sub-criteria groups.

The cause factors were defined in terms of the relationship value $\left(\tilde{D}_i - \tilde{R}_j\right)$. This value can be either positive or negative. Consequently, the sub-criteria which affected the collision of two passenger trains consisted of X_5, X_6, X_7, X_9, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, and X_{16}. On the other hand, the sub-criteria which were influenced by the collision of two passenger trains involved X_1, X_2, X_3, X_4, X_8, X_{10}, and X_{17}.

The cause sub-criteria groups have to be discovered and managed due to the fact that they have a significant impact on the occurrence of train accidents. Identifying and controlling these sub-criteria can be useful for reducing train accidents.

4.4.1 Cause factors

In order to clearly assess the most common and critical train accidents, it is really important to study the cause factors. As shown in Fig. 4, X_{12} (The curvature of the train course) had the highest $\left(\tilde{D}_i - \tilde{R}_j\right)$ value (1.13) among all of the factors in the cause group. This shows that X_{12} had a more significant impact on the whole process. Moreover, X_{16} (Absence of the ground aid) was the second most important cause factor. In addition, X_7 (Lack of a mechanism to identify the weaknesses of the employees' skills) had the third highest $\left(\tilde{D}_i - \tilde{R}_j\right)$ value (0.59), which means that it had a considerable influence on the entire process. This sequence continues with X_5 (Radiotelephone's expert system) and X_9 (Unrealistic nature of most ATC warnings). Therefore, it seems that the other cause factors had relatively moderate impacts on the collision of the two passenger trains.

4.4.2 Effect factors

Analyzing the factors in the cause-effect relation diagram in Fig. 4 reveals that the influential factors can easily be affected by the other factors. According to this figure, X_{17} (The capability of a proper reaction to reduce the impact of an event after its occurrence or to prevent the casualties, damage, and loss) had the highest $(\tilde{D}_i + \tilde{R}_j)$ value (8.07) in the effect factor group. Moreover, X_2 (Deactivation of the ATC system), X_4 (Lack of the order to exit ATC system), X_8 (Defects in the ATC system), and X_{10} (Failure to operate the ATC system efficiently) had great impacts on the whole process as effect factors.

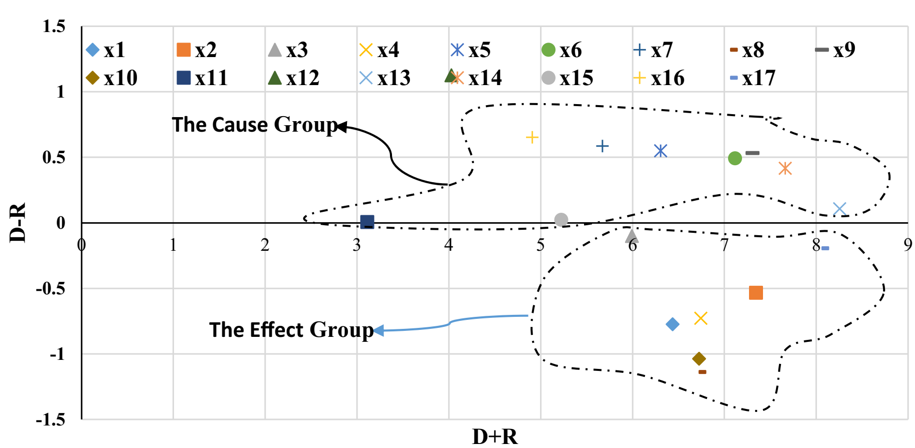

Fig. 4 The cause and effect diagram

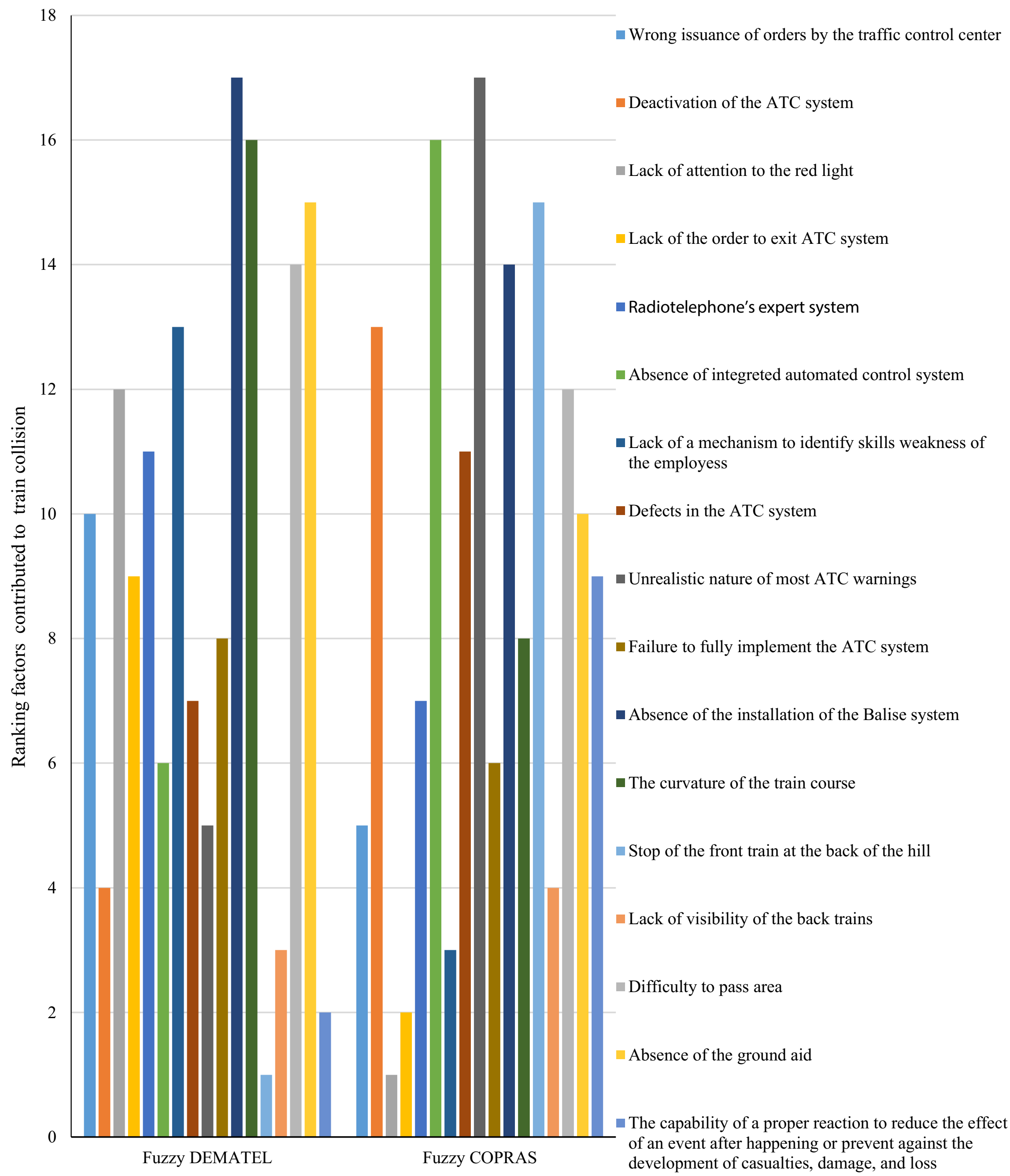

Fig. 5 Ranking factors in train collision among risk factors in the collision of two passenger trains

The obtained results of the two proposed Fuzzy MCDM approaches in Fig. 5 showed that the most critical risk factor in the collision of two passenger trains was lack of attention to the red light based on Fuzzy COPRAS. This factor was classified as an individual factor. However, unrealistic nature of most ATC warnings was ranked as the least important risk factor. This result is in line with the results of the similar studies which have noted that this factor has been the least important factor in train collisions (Baysari et al. 2008; Eftekhari et al. 2018). In addition, according to Fuzzy DEMATEL approach, it can be said that the curvature of the train course was the most causative environmental factor in the collision of two passenger trains. Similarly, this result is supported by the results of other studies which have mentioned this factor as the environmental factor in train collisions (Buck 1963; Eftekhari et al. 2018; Matsumoto et al. 2016). Moreover, the capability of a proper reaction to reduce and prevent the collision of two passenger trains was ranked as the most effective factor in the present study. Likewise, other studies

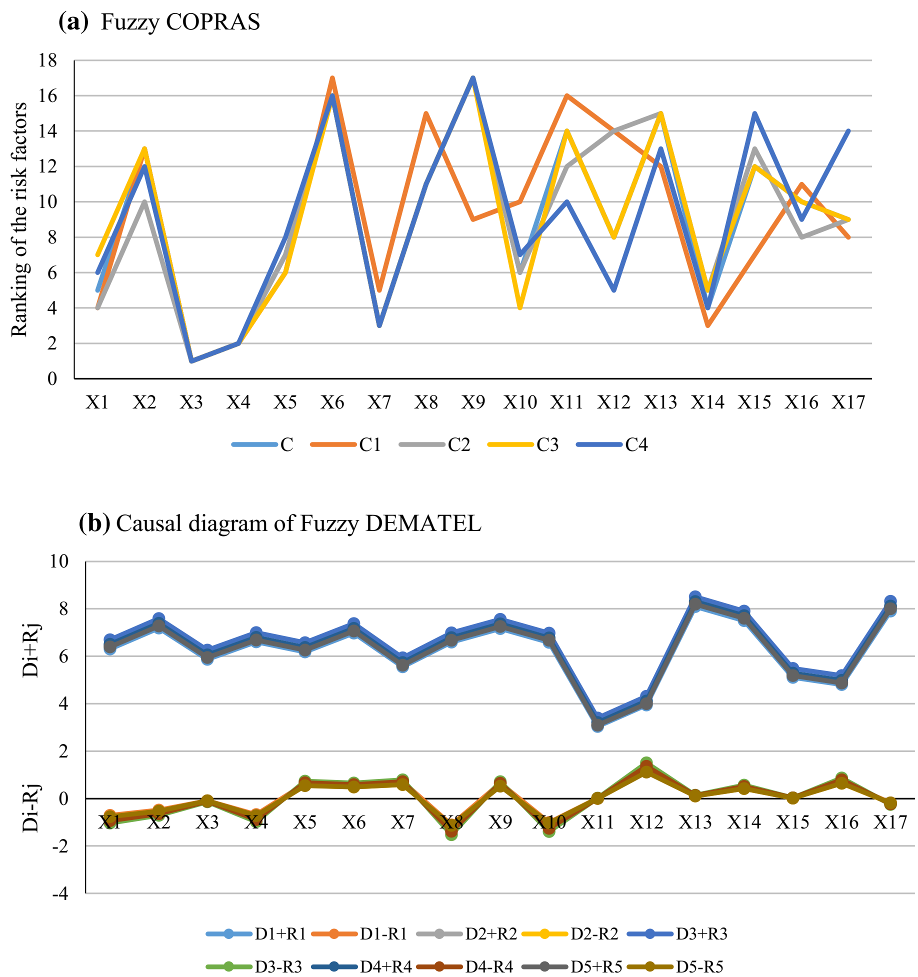

Fig. 6 Sensitivity analysis of two proposed methods

Table 14 The sensitivity analysis of proposed methods

Criteria		C_1	C_2	C_3	C_4
Fuzzy COPRAS					
Original CLEs		M	H	H	M
Case 1		L	H	H	M
Case 2		M	M	H	M
Case 3		M	H	VH	M
Case 4		M	H	H	VL
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Fuzzy DEMATEL					
Expert 1	0.20	0.10	0.10	0.10	0.10
Expert 2	0.10	0.20	0.10	0.10	0.10
Expert 3	0.10	0.10	0.20	0.10	0.10
Expert 4	0.10	0.10	0.10	0.20	0.10
Expert 5	0.10	0.10	0.10	0.10	0.20

have highlighted this factor as one of the most important factors in the reduction of train collisions in the future (Klockner and Toft 2015; Zhan et al. 2017; Eftekhari et al. 2018).

5 Sensitivity analysis

Sensitivity analysis was performed to compare the two proposed methods with each other. The results of the comparison are shown in Fig. 6 and Table 14. Based on Fuzzy COPRAS, a sensitivity analysis was carried out to investigate the validation of the proposed methodology with respect to the 4 cases which are shown in Table 14. In order to constitute different cases for the criteria, the comparative linguistic expressions (CLEs) of a given criterion were changed, while the CLEs of the other criteria remained fixed (see Table 14). For instance, in Case 1, the CLE 'H' of criterion C_1 was replaced with 'L'. Nonetheless, the other 3 criteria remained fixed. According to the

Table 15 The ranking of alternatives with respect to the considered fuzzy MCDM methods and performance scores

Alternatives	Fuzzy MCDM Methods		Performance scores
	Fuzzy COPRAS	Fuzzy DEMATEL	
X_1	5	10	7
X_2	13	4	5
X_3	1	12	2
X_4	2	9	6
X_5	7	11	11
X_6	16	6	12
X_7	3	13	16
X_8	11	7	8
X_9	17	5	10
X_{10}	6	8	9
X_{11}	14	17	17
X_{12}	8	16	14
X_{13}	15	1	1
X_{14}	4	3	4
X_{15}	12	14	13
X_{16}	10	15	15
X_{17}	9	2	3

sensitivity analysis of different cases for the fuzzy COPRAS method, the ranking results, which are provided in Fig. 6a, show that X_3 is the most critical risk factor and X_9 is the least critical factor in the collision of two passenger trains. Despite the small changes in ranking results, the ranking of the alternatives has acceptable stability across the different cases. Therefore, it can be inferred that the results of the proposed methodology are stable and the initial ranking result is reliable, since the most critical risk factor (X_3) and the least critical risk factor (X_9) are relatively insensitive to the changes in criteria weights.

In Fuzzy DEMATEL, sensitivity analysis was performed by assigning different weights to railway experts to check the consistency and to assess the variation in cause-effect relationships. In order to perform the sensitivity analysis more efficiently, first, 5 experts were randomly selected. Next, a greater weight was assigned to one expert. Then, weights for other experts were kept unchanged as shown in Table 14. The results in Fig. 6b show that the ranking of cause and effect factors remained unchanged in all of the scenarios. The sensitivity analysis produced robust and valid results which were close to the real preferences of the experts. As a result, the experts' understanding of the causes of collision of two passenger trains in railway industry was adequate for this study. In addition, The Spearman's correlation coefficients were calculated for evaluating the correlations between the ranking results of the considered fuzzy MCDM methods and the performance scores (see Table 15) which were obtained by experts. Based on the results, there was a high correlation ($r \geq 0.7$) between Fuzzy DEMATEL and the performance scores. Moreover, it was higher than the correlation ($r \geq 0.2$) between Fuzzy COPRAS and the performance scores and ranked the risk factors in a better way.

6 Conclusions

Identifying critical risk factors in the collision of two passenger trains helps railway experts and engineers to prevent the collisions and to promote railway transport operation in regard to train accidents in the future. Based on these issues, first, this study made an effort to identify the practical risk factors in the collision of two passenger trains in "Haft Khan'" station using questionnaire survey and field observation. Second, it adopted two Fuzzy COPRAS and Fuzzy DEMATEL approaches to evaluate and rank risk factors based on railway industry exports' opinions about 4 practical risk main criteria and 17 risk sub-criteria. The results of the evaluation and ranking of risk factors in the collision of two passenger trains are provided below:

1. With regard to fuzzy COPRAS approach, the risk ranking in descending order was X_3, X_4, X_7, X_{14}, X_1, X_{10}, X_5, X_{12}, X_{17}, X_{16}, X_8, X_{15}, X_2, X_{11}, X_{13}, X_6, and X_9. Therefore, the critical risk factor with the highest rank was X_3 (Lack of attention to the red light), and the critical factor with the lowest rank was X_9 (Unrealistic nature of most ATC warnings).
2. According to Fuzzy DEMATEL approach, the factors were categorized as cause (X_5, X_6, X_7, X_9, X_{11}, X_{12}, X_{13}, X_{14}, X_{15} and X_{16}) and effect (X_1, X_2, X_3, X_4, X_8, X_{10}, and X_{17}) sub-criteria groups. Therefore, X_{12} (The curvature of the train course) had the highest $\left(\tilde{D_i} - \tilde{R_j}\right)$ value (1.13) among all of the factors in the cause group. On the other hand, X_{17} (The capability of a proper reaction to reduce the impact of an event after its occurrence or to prevent the casualties, damage, and loss) had the highest $(\tilde{D_i} + \tilde{R_j})$ value (8.07) in the effect factor group.
3. Sensitivity analysis for Fuzzy COPRAS and Fuzzy DEMATEL models showed that the most and the least critical factors were relatively insensitive to the changes in criteria weights for both of the models. Moreover, a comparison between the two proposed models showed that Fuzzy DEMATEL model indicated rankings which were similar to the performance scores of the experts due to the higher obtained Spearman's correlation coefficient. Therefore, it was

concluded that Fuzzy DEMATEL model played an important role in the prioritization of risks factors in railway risk assessment. According to this model, the risk factor with the highest rank was the stop of the front train at the back of the hill. However, the risk factor with the lowest rank was the absence of the installation of the Balise system.
4. Based on the findings of the present study, the environmental and individual factors including the stop of the front train at the back of the hill due to the curvature of the train course and the lack of attention to the red light need to be modified by improving the ATC train system and reforming geometric design of train course in order to reduce the number of train collisions. In addition, adopting fuzzy fault tree analysis and fuzzy clustering approaches helps railway engineers and managers to prioritize critical risks in train collisions appropriately and to improve the safety of the railway transportation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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