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**RESEARCH ARTICLE**

# EVALUATION AND ANALYSIS OF RISK FACTORS IN RAILWAY ACCIDENTS IN TÜRKİYE

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## Abstract

The main purpose of transportation is to transport passengers and cargo in the shortest possible time, safely and economically. In order to achieve this goal, the safety factor constitutes one of the most basic elements of transportation. In recent years, many countries have made various legal regulations to increase the safety and efficiency of the railway sector and have produced targets and policies to reduce railway accidents and loss of life. In this study, the current situation of the number of accidents, deaths, and types of accidents occurring in Turkish railways was shown, and a statistical comparison was made with the European Union (EU). When we evaluate it from Türkiye's perspective, it seems that it has some deficiencies in this regard compared to the European Union countries. The main purpose of the study is to examine railway accidents in Türkiye. In this context, the factors that may cause an accident are classified into 58 parameters. AHP (Analytic Hierarchy Process) from MCDM (Multi Criteria Decision Method) and L-Decision Matrix were used, and risk analysis was carried out by scoring likelihood and severity. Risk analysis was evaluated for the first time in Türkiye by employees of investor companies, investor organizations, and consultancy firms that built railways. In conclusion, the riskiest activity of the sector stakeholders that constitute the infrastructure was determined as uncontrolled entrances of pedestrians to level crossings as a high risk with the L-Decision Matrix method and the B4 risk index score. By using the AHP method, it is obtained uncontrolled pedestrian access to level crossings has a risk importance weight of p = 0.28 (0-1), and uncontrolled access to the road due to closures has a risk importance weight of p = 0.21. (0-1). Suggestions were made to prevent accidents.

## Keywords

Railway,
Railway Accident,
Risk,
L-Decision Matrix,
AHP

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## 1. INTRODUCTION

Railways, which played a decisive role in the development of societies, are critical in ensuring balanced transportation policies by being in a very favorable position to all modes of transportation due to Türkiye's geopolitical and geostrategic position in the future perspective. In this respect, according to the 2053 investment projections, it is estimated that the investments to be made in railways will constitute one-third of all transportation modes [1].

The way to provide safe, balanced, and economical railway transportation is through security. Since there are no limits to security measures, engineering studies are carried out to ensure acceptable costs and maximum security together at the optimum points, which are essential here. However, the risk of accidents will always exist because there is mobility on the railways, and transportation by rail cannot be completely isolated from external environments. For this reason, many measures have been taken in the country's policies. According to the 2022 Safety Report of the International Railway Association, it is observed that between 2016 and 2021, the number of accidents, the number of serious accidents per million train-km, the number of deaths, the number of deaths per million train-km tend to decelerate [2]. However, with all the technical knowledge, rules, and technological advances in the world, the safety elements that need to be improved in railway safety continue to exist.

In railways, an accident is defined as an unwanted, unexpected, sudden, and unintentional event or chain of events with harmful consequences such as property damage, death, or injury. A significant accident is an accident involving at least one moving railway vehicle in which at least one person is killed or seriously injured, causing significant damage to the vehicle or even structures or the environment, or extensive disruption to traffic, and costing €150,000 or more [3]. Because of the importance of the subject, lots of studies regarding railway accidents were carried out. In a study examining Slovak railways by collecting various accident reports, models were developed, and the accident risk of the railway system was evaluated [4]. In a study conducted in France, railway accident risks were analyzed and predicted using machine learning technique [5]. In a study conducted in Taiwan using accident counting data models, risk factors at level crossings were investigated [6].

Many studies on railway accidents and railway safety were conducted in Türkiye. Akbayır statistically examined various accident data in different years after 2003, showing that the number of accidents and deaths decreased. It has been concluded that by increasing the number of active level crossings, the crossing collision fatality rate will be reduced; active level crossings should be built in the right places; and signaling systems are not used correctly [7]. Kıyıldı examined the statistical data on level crossing accidents between 2000 and 2019 and suggested that the number of level crossings should be reduced or converted to under/overpasses, and the crossings should be modernized and equipped with barriers [8]. Ilıcalı, on the other hand, examined railway fencing in the world, stated that the accidents along the line were due to unauthorized crossings and that this was mainly due to need, and made various determinations and evaluations such as preventing pedestrians from entering the railway lines and building underpasses and overpasses in areas in need of passage [9]. Ghanem and Xuemei compared Türkiye's railway safety with EU countries using Charnes, Cooper, and Rhodes (CCR) and Banker–Charnes–Cooper (BCC) analyses, which are basic data envelopment analyses; line length/km, number of locomotives and wagons, number of passenger transport vehicles and number of goods transport wagons were used as input. According to the analysis results, using the number of accidents, the number of deaths and the number of injured as outputs, they concluded that Türkiye was more successful than EU countries in reducing the number of accidents and deaths [10].

Among related studies conducted in Türkiye, there is a study conducted using the Fuzzy SWARA (Step-Wise Weight Assessment Ratio Analysis) method. In this study, eight parameters were determined, and railway infrastructure periodic maintenance was ranked first, railway superstructure maintenance second, and rolling stock maintenance third. Level crossings, railway fencings, and tunnel fire safety were ranked last, respectively. Thus, the importance of the parameters chosen in railway safety in guiding the outcome of the assessment and the experience of individuals can influence the outcome [11]. Özarpa, Avcı and Kınacı carried out signalization system risk analysis using AHP analysis with five experts and found that signalization systems, with 26.65%, and switching systems, with 23.47%, were the priority risk topics [12].

The primary purpose of this study is to ensure safe transportation by preventing the risk factors determined by experts on the railway. In this direction, firstly, the number of railway accidents occurring in Türkiye and European Union countries and the types of accidents were examined separately and comparatively. In the second part of the study, the risks that may cause accidents to occur on the railways were determined by literature review and expert opinions. The identified risks have been evaluated in accordance with the experiences and opinions of the investor organizations and consultant teams operating on the railway. There are studies in the literature where AHP and L-Decision Matrix are used together in risk analysis [13, 14]. These methods were also used in this study. In the study, 58 factors determined as the cause of railway accidents were examined in five different groups. The ability of AHP to solve complex problems and the ease and practicality of L-Decision Matrix are the reasons why these two methods were used in this study. As a result of these methods used, the risks with the highest rate that can cause an accident on the railways have been identified. In addition, in this study, suggestions have also been made about the measures that should be taken to address risks in order to reduce accidents on railways. Our study is essential in that it includes an overall assessment of railway safety in Türkiye over 58 different factors, with 20 expert opinions, and for the first time directly from the perspective of infrastructure stakeholders. These factors will be used as "*Criteria*" in AHP application of our study. It is also important to strengthen the compatibility of the concerns of infrastructure stakeholders with statistics.

When the sample sizes in similar studies are examined, it is thought that the number of determined criteria for railway safety evaluated and the number of participants is sufficient for this study. Criteria that pose the risk have been prepared comprehensively. However, in addition to the criteria examined in the study, different criteria that may cause railway accidents can also be examined. In certain areas, different risk analysis methods may use different numbers criteria. The study period is limited to the years 2002-2021. Data after the Covid 19 pandemic have not been examined.

## 2. RAILWAY ACCIDENT IN TÜRKİYE AND THE COMPARISON WITH EU COUNTRIES

In this part of our study, which is prepared to contribute to the provision of safe railway transportation in Türkiye, the number of accidents occurring in Türkiye and European Union countries and the types of these accidents are examined. A statistical introduction about railway accidents in Türkiye and various information are given. Train-km was used as the scale. Train-km is the unit of measurement representing the distance a train travels one kilometer. Within the scope of data, TCDD (General Directorate of Turkish State Railways) Statistical annuals [15-19] and TUIK (Turkish Statistical Institute) transport statistics [20], European Commission Statistical Pocketbook [21] and Eurostat Railway statistics on railway accidents were compiled and examined [22-24]. The number and types of accidents in Türkiye were compared with those in EU countries. The number of railway accidents per million train-km mobility in Türkiye between 2002 and 2021 is given in Figure 1. The number of deaths per million train-km mobility in Türkiye between 2002 and 2021 is given in Figure 2. Figures 1 and 2 are obtained by dividing the number of accidents and fatalities in those years by the train mobility values in the same years.

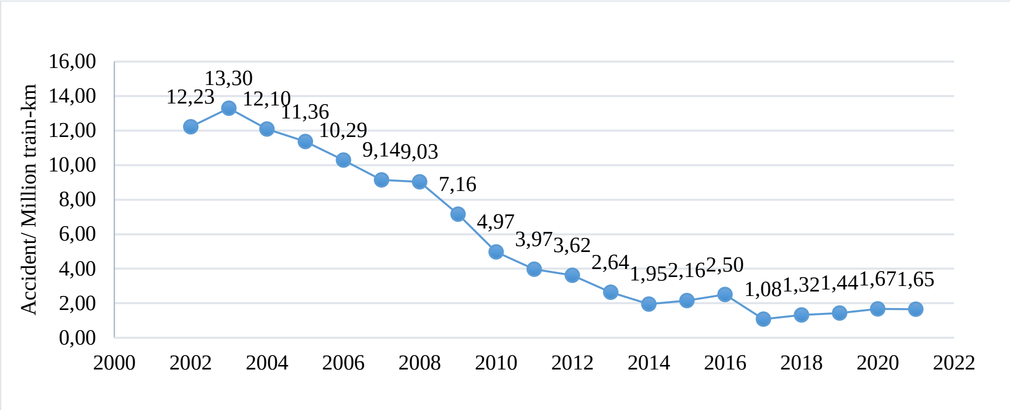


**Figure 1.** Number of accidents per million train-km between 2002-2021 in Türkiye [15-20]

The values shown in Figure 1 are obtained by dividing the number of accidents that occurred in those years by the million train-km value in the same year. While there were 12.23 accidents per million train-km in 2002, this rate decreased by 86% to 1.65 in 2021.

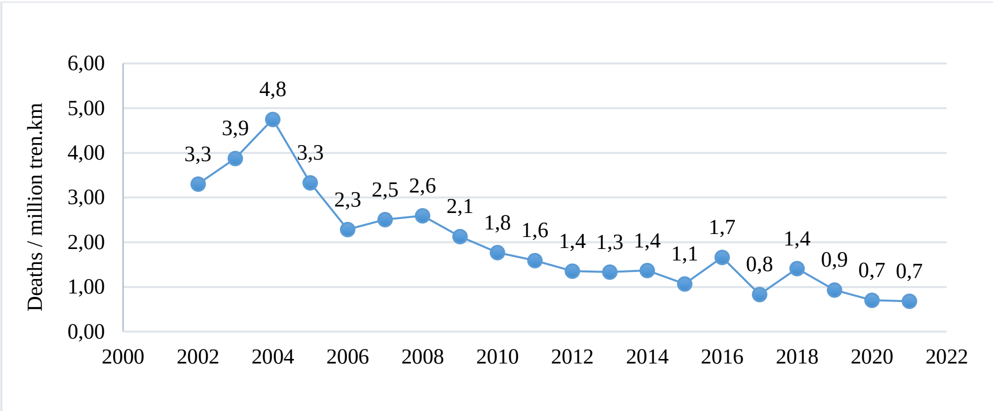


**Figure 2.** Number of deaths per million train.km between 2002 and 2021 in Türkiye [15-20]

According to Figure 2, the highest death rate occurred in 2004, with 4.8 deaths per million train-km, and it is seen that it showed a general decreasing trend over the years, decreasing from 3.3 in 2002 to 0.7 deaths in 2021.

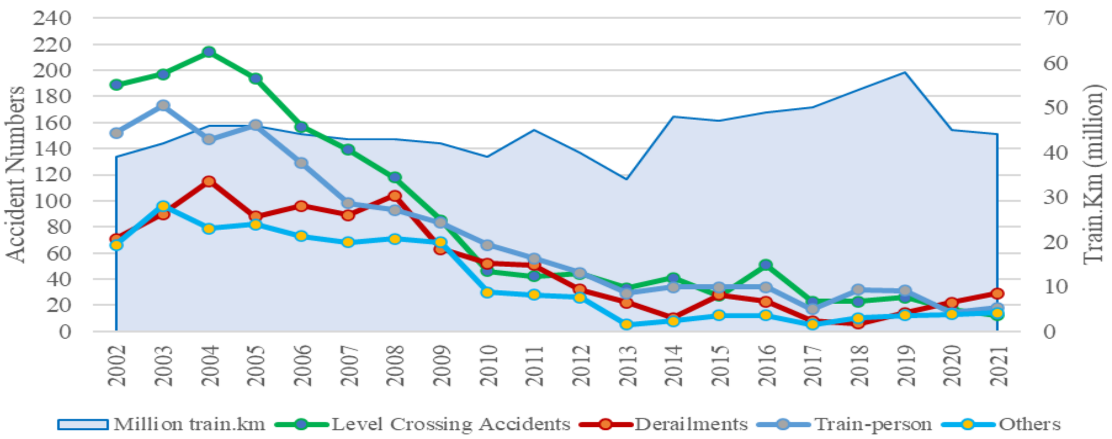


**Figure 3.** Types of railway accidents in Türkiye between 2002 and 2021 [15-20]

Types of railway accidents in Türkiye between 2002 and 2021 are given in Figure 3. According to Figure 3, from 2002 to 2021, it was observed that level crossing accidents decreased by 93% from 189 to 12; human accidents caused by moving trains decreased by 88% from 152 to 18; derailment cases decreased by 60% from 71 to 29; and collisions decreased by 57% from 21 to 9. At the beginning of the 2000s, level crossing accidents and personal collisions were among the highest types of accidents, while by the 2020s, it was observed that derailment and train personal collisions were higher, respectively.

The number of accidents per million train-km in Türkiye and EU countries and their comparison are shown in Figure 4. Figure 5 shows the number of deaths per million train-km between 2010 and 2020. Figures 4 and 5 are obtained by dividing the 11-year total number of accidents and fatalities by the total number of train movements.

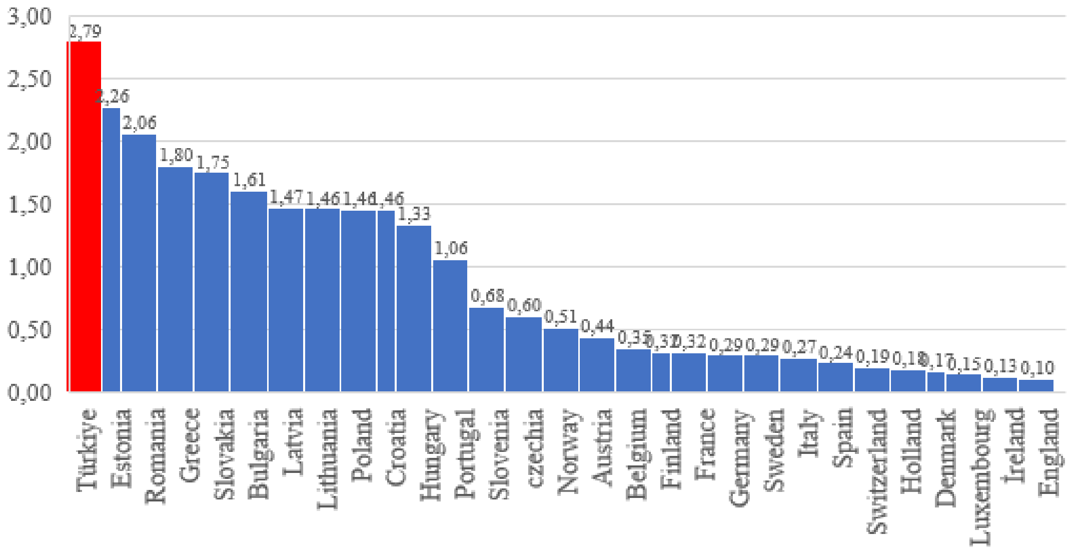


**Figure 4.** Number of accidents per million train-km in Türkiye and EU countries (2010-2020) [20-21]

When the total data for the last 11 years is examined in Figure 4, it is seen that the highest number per million train-km is in Türkiye. The highest number of accidents per million train-km is seen in Türkiye with 2.79, followed by Estonia with 2.26, and Romania with 2.06. Additionally, the lowest number of railway accidents per million train-km occurs in England with 0.1 and Ireland with 0.13. In other words, in the same years, the number of railway accidents occurring in Türkiye is approximately 27 times more than in England, 22 times more than in Ireland, 16 times more than in Denmark, and 1.5 times more than in Greece.

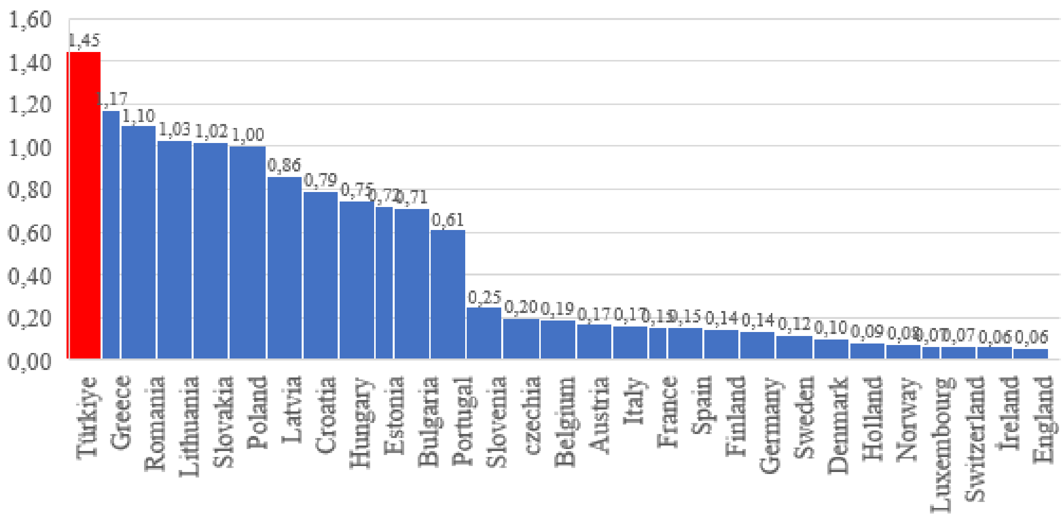


**Figure 5.** Number of deaths per million train-km in Türkiye and EU countries (2010-2020) [20, 21]

When Figure 5 is examined, the highest number of deaths is seen in Türkiye, with 1.45. Türkiye is followed by Greece with 1.17, Romania with 1.10 and Lithuania with 1.03. The lowest number of deaths per million train-km is England and Ireland with 0.06, and Switzerland with 0.07. In other words, when the number of deaths per million train-km between 2010 and 2020 is examined, the rate in Türkiye is approximately 26 times that of England, 24 times that of Ireland, 22 times that of Switzerland, and 1.23 times compared to Greece. There appears to be a higher number of deaths. Table 1 includes the number of railway accidents in European Union-27 countries and Türkiye between 2010 and 2020. European Railway Agency data was used [22].

**Table 1.** EU-27 and Türkiye railway accidents by type between 2010 and 2020 [22]

| | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| European Union | Collision | 79 | 70 | 87 | 80 | 121 | 123 | 99 | 102 | 109 | 103 | 110 | 1,083 |
| | Derailment | 89 | 85 | 94 | 100 | 93 | 72 | 62 | 88 | 74 | 73 | 69 | 899 |
| | Level Crossing | 585 | 506 | 563 | 498 | 495 | 465 | 424 | 456 | 442 | 432 | 350 | 5,216 |
| | Human accidents caused by moving trains | 1,354 | 1,395 | 1,158 | 1,121 | 1,186 | 989 | 1,042 | 1,034 | 939 | 794 | 685 | 11,697 |
| | Others | 122 | 88 | 90 | 96 | 127 | 114 | 115 | 97 | 102 | 113 | 117 | 1,181 |
| Türkiye | Collision | 8 | 8 | 4 | 2 | 2 | 4 | 6 | 2 | 6 | 4 | 9 | 55 |
| | Derailment | 52 | 51 | 32 | 22 | 10 | 28 | 23 | 8 | 6 | 14 | 22 | 268 |
| | Level Crossing | 46 | 42 | 44 | 33 | 41 | 27 | 51 | 23 | 23 | 26 | 17 | 373 |
| | Human accidents caused by moving trains | 84 | 73 | 58 | 31 | 37 | 36 | 36 | 19 | 33 | 33 | 14 | 454 |
| | Others | 4 | 3 | 9 | 1 | 3 | 6 | 4 | 1 | 3 | 6 | 4 | 44 |

Percent accident rates of railway accidents in Türkiye and the European Union countries between 2010 and 2020 are shown in Figure 6.

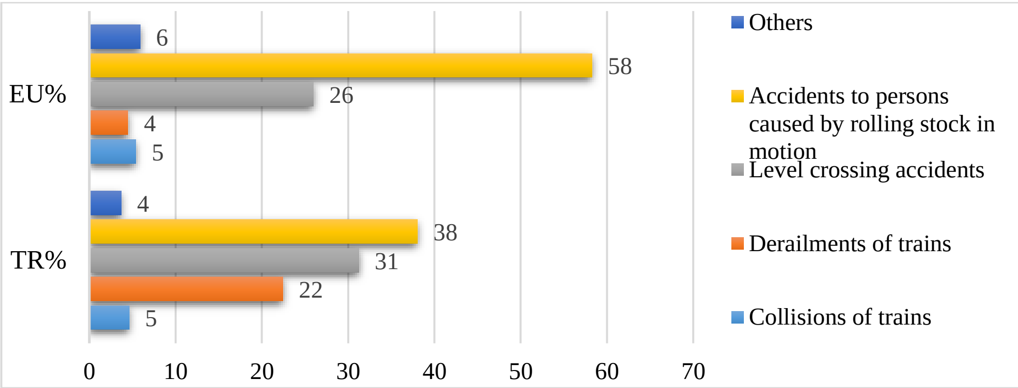


**Figure 6.** Railway accidents in the European Union (EU) and Türkiye (TR) by type (2010-2020) [22]

When Figure 6 is examined, it is observed that while train-person collisions are seen at a very high rate throughout the European Union and Türkiye, there is a much higher rate of derailment accidents in Türkiye compared to European countries. According to D-Rail reports supported by the European Commission, the causes of derailment in Europe between 2005 and 2010 were revealed as axle breaks, track expansion, wheel defects, asymmetric loading, line twists, rail defects, and spring and suspension defects, respectively [25]. Statistical data regarding the causes of delays in Türkiye are not sufficient, and it is thought that criteria such as inadequacy of our signaling and line infrastructure, transportation at speeds higher than the limits allowed by the infrastructure, road twists and gauge defects, and component failures related to vehicles are effective.

## 3. MATERIAL AND METHOD

In the study, the risks that cause accidents on the railway were prepared by taking into account the literature and the opinions of experts and analyzed according to the opinions of 20 experts. All of these evaluations are included in the study conducted by Eser [26]. The expert's scorings are attached in the appendix. These experts consist of four head of department-level investor organization (public) employees, nine consultant company employees, and seven contractor company site chiefs and controllers who have completed at least one work in the railway sector. The experts are two mechanical engineers, five electrical-electronics and/or communication engineers, and 13 civil engineers according to their professions. Thirteen participants were interviewed face to face, and seven people were contacted online. The results of this evaluation aim to determine the risks with the highest rate and to take precautions for safe railway transportation in this direction.

This study used L-Decision Matrix and AHP techniques to rank the risks, respectively. However, these methods are listed in alphabetical order in the study. There are differences in the application of AHP and L-Decision Matrix. The AHP method, which can solve complex and difficult-to-understand problems [27] and can rank, was used to weigh and rank the identified risks. One of the biggest advantages of AHP is that it helps decision makers to separate a complex issue in a simpler way [28]. For this reason, the AHP method was deemed appropriate for ranking the fifty-eight criteria which are the factors determined for railway safety in this study. The application of AHP was realized by taking the geometric average of twenty experts' opinions. According to both method procedures, the risks were ranked and compared at the end of the study. The L-Decision Matrix (5x5) method is an easy-to-apply method where risks are identified and scored, and cause and effect relationships are included in the evaluation. In the L-Decision Matrix, the evaluation is based on the arithmetic average. Risks are ranked by the arithmetic average of the opinions of each of the twenty experts.

Currently, various studies are being carried out to analyze the risks of AHP and L-Decision Matrix. Kılıç used the Fuzzy AHP method in his study to study the risks related to marine accidents in the Istanbul Strait [29]. Arslan and Turan analyzed the factors causing marine accidents by SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and found the weights of these factors using the AHP method [30]. Bayazit used the AHP method for safety assessment at railway-level crossings in his study [31]. Bureika and his colleagues used the AHP technique to examine factors that may threaten railway safety by aiming to prevent accidents on railway lines in Lithuania in their study [32]. Liu and his colleagues used AHP, MAWR (Maximum Absolute Weighted Residual), MEM (Maximum Entropy Method) techniques for risk assessment in the safety analysis of railway signaling systems in their study [33]. Similarly, the 5x5 L-Matrix method is one of the methods used to analyze possible risks. For example, Uray used a matrix to determine the possible effects of risks in railway maintenance [34], and Damat and Utlu used a matrix to expand the scope of work in metro stations in Istanbul [35]. In their studies, Bayraktar and his colleagues aimed to determine the possible effects of earthquake-related non-structural risks in schools using the 5x5 L-Matrix method [36]. Information about the methods and their application are described below.

### 3.1. AHP Method

AHP developed by Saaty, is one of the most popular techniques for complex decision-making problems. There are lots of advantages of AHP. Some of these are its flexibility, intuitive expression to decision makers, and ability to check inconsistencies. To be simple, the method of AHP is the most important advantage. Also, the biggest advantage of AHP is that it can easily form groups to handle inconsistencies in judgments, which is the case when compared to other multicriteria methods of AHP [37]. The AHP method is expressed as a technique based on a pairwise comparison of criteria to determine their superiority over each other. It is a widely used method. The application stages of AHP are listed below.

**Step 1:** In the first step of the AHP method, the problem is defined.

**Step 2:** Hierarchy is created, and the purpose of the hierarchy is revealed. Criteria, and alternatives are included.

**Step 3:** Pairwise comparisons matrix is created. Each criterion is compared in pairs according to the importance scale shown in Table 2 [38].

**Table 2.** Importance Levels (Scale) [38]

| Importance Level | Explanation |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance. |
| 7 | Very strong importance. |
| 9 | Extreme importance. |
| 2, 4, 6, 8 | Intermediate values |

**Step 4:** Pairwise comparison matrices are normalized. The weights of criteria based on generated pairwise comparison matrices are calculated. For this calculation, the column sum of the pairwise comparison matrix is taken and divided by the column sum corresponding to each element of the pairwise comparison matrix, and a normalized pairwise comparison matrix is obtained. Formulization is shown below (1).

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix} \qquad b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{1}$$

Here, aij; represents the i-th row and j-th column element of the comparison matrix, and bij represents the i-th row and j-th column of the normalized matrix.

**Step 5:** Then, the values of each row are summed and divided by the matrix size to determine the importance values (Wi) for each criterion. Equation is shown below (2).

$$C = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \qquad w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{2}$$

**Step 6:** Since the comparisons are subjective, the consistency rate must be calculated. If the calculated rate is below 10%, it is considered sufficient. Whether the evaluation is consistent or not is determined by the consistency rate. The lower the consistency rate, the more consistent the evaluation. If the consistency ratio is higher than 0.1, that evaluation is not consistent. Accordingly, It is returned to the pairwise comparison matrix, and the process is performed again. After all these processes, the decision matrix is created [39]. In order to calculate the CR value, the largest eigenvector (λmax) value of the pairwise comparison matrix must first be calculated. Formulization is shown below in 3., 4., and 5. equations.

where i= 1, 2,..., n and j= 1, 2,..., n,

$$[a_{ij}]_{nxm} * [w_i]_{nx1} = [d_i]_{nx1} \tag{3}$$

$$\lambda max = \frac{\sum_{i=1}^{n} \frac{di}{wi}}{n} \tag{4}$$

In calculating the consistency ratio, the Randomness Index (RI), depending on the number of criteria (n) included in the comparison, is used. The RI values determined according to the n values are shown in Table 3. The calculation of the CR value according to the obtained inputs is shown in equation 5.

$$CR = \frac{\lambda - n}{(n-1).RI} \tag{5}$$

**Table 3.** Randomness index (RI)

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0 | 0 | 0,58 | 0,9 | 1,12 | 1,24 | 1,32 | 1,41 | 1,45 | 1,49 | 1,51 | 1,48 | 1,56 | 1,57 | 1,59 |

In the AHP process, the criteria weights are determined as a result of surveys conducted with experts on the subject, that is, based on a group decision. Accordingly, three approaches can be used. These are the consensus of experts on a certain criterion, voting on options when experts cannot express a common opinion, and geometric mean approaches. In the geometric mean approach, the joint decision of n experts is reduced to a single value using the geometric mean method. In the geometric mean approach, "k", "i" and "j" stand for "expert", "criterion","criterion", respectively. "kij" is the value of the comparison of the i. and the j. criteria according to k. expert. The geometric mean method is one of the most used approaches, as shown in equation 6 [39].

$$a_{kij} = [a_{1ij} * a_{2ij} * a_{3ij} * \ldots * a_{nij}]^{1/n} \quad (6)$$

### 3.2. L-Decision Matrix Method

Known as the American Military standard "MIL_STD_882-D", 5x5 Matrix diagram (L-Type Matrix), one of the widely used risk assessment matrix approaches and was developed to meet the system security program requirement, is used especially in evaluating the cause-effect connection [40]. The method is one of the most frequently used methods because it is easy, and even one person can do it. The 5x5 Risk Matrix consists of two main dimensions: likelihood and severity. Likelihood refers to the probability or chance of a hazard occurring, while severity relates to the potential impact or consequences of that hazard. Each dimension is divided into five levels, creating a matrix with 25 cells. To put it briefly, the L-Type Matrix (L-Decision Matrix) method is a subjective evaluation method. Therefore, the reliability of subjective results depends on the experience of the specialized people who make the application. Formulization of risk is shown below (7).

$$\text{Risk} = \text{Likelihood} \times \text{Severity} \quad (7)$$

The L-decision matrix risk score evaluation matrix will be considered as follows, and the areas indicated in red refer to the sections that are unacceptable areas, and it is necessary to intervene and stop work, and definitely not to start work until it reaches an acceptable risk level. Yellow areas refer to areas that need to be intervened as soon as possible using risk mitigation measures, while green areas refer to areas that can be intervened in the longer term or do not need additional controls to reduce the risk. The analysis results of the risks were evaluated according to the risk likelihood score (Table 4), severity score (Table 5), risk matrix (Table 6) and risk acceptance levels (Table 7) prepared within the scope of the study.

**Table 4.** Likelihood score [40]

| (It refers to the probability of an accident or event.) | | | |
|---|---|---|---|
| **Grade** | **Probability of Occurrence** | **Definition** | **Period** |
| A | Very High | The incident may occur at any moment. | Daily |
| B | High | The event may occur frequently. | 2 days - 1 month |
| C | Medium | The incident may occur Decently from time to time. | 1 month - 1 year |
| D | Low | The event may occur rarely. | 1 year- 10 years |
| E | Very Low | The event can occur very, very rarely. | More than 10 years |

The likelihood table prepared to determine the risk score is classified as grade related to the criterion, probability of occurrence, definition, and period. Ranges are as shown in the table.

**Table 5.** Severity score [40]

| (The severity of an accident or incident in the situation where it occurred) | | |
|---|---|---|
| **Grade** | **The Severity of the Incident** | **Depiction of possible harm or loss** |
| 5 | Disaster | Multiple deaths / severe environmental damage / severe property damage |
| 4 | Severe | One death/significant environmental damage/significant property damage |
| 3 | Medium | Multiple severe injuries/not worth recording environmental damage/property damage that is not worth recording |
| 2 | Slight | Single serious injury / minor environmental damage / minor property damage |
| 1 | Insignificant | Minor injury/possible minor environmental and property damage |

Severity table is prepared to determine the risk score. It is classified according to the severity of the incident, description of possible harm or loss, and its grade. The ranges are shown in Table 5.

**Table 6.** Railway risk matrix (5x5 L Type Matrix)

| | | | Severity | | | | |
|---|---|---|---|---|---|---|---|
| | | | Disaster | Severe | Medium | Slight | Insignificant |
| | | | 5 | 4 | 3 | 2 | 1 |
| Probability | Very High (Once a week/day) | A | A5 | A4 | A3 | A2 | A1 |
| | High (Once a month) | B | B5 | B4 | B3 | B2 | B1 |
| | Middle (Several times a year) | C | C5 | C4 | C3 | C2 | C1 |
| | Very little (Once a year) | D | D5 | D4 | D3 | D2 | D1 |
| | Impossible/rare | E | E5 | E4 | E3 | E2 | E1 |

The risk matrix was created by the authorsusing the literature, depending on the likelihood and severity values.

**Table 7.** Risk acceptability levels for railways of Türkiye

| Risk Index | Risk Category | Action |
|---|---|---|
| A4, A5, B5 | Unacceptable Risks | The identified works and transactions should be stopped immediately, and activities should be prevented if risk reduction processes are applied and the current risk cannot be reduced to the desired level. |
| A3, B4, C5 | High-Grade Risks | Until the identified risks are reduced, work and operations should be stopped, and the risk should be reduced with additional control processes. The continuation of the work should be re-evaluated according to the data obtained as a result of the risk reduction methods. |
| A2, B2, B3, C3, C4, D4, D5, E5 | Moderate Risks | It is necessary to implement risk reduction activities, and the business can be continued by taking responsibility. |
| A1, B1, C1, C2, D1, D2, D3, E1, E2, E3, E4 | Low-Grade Risks | Existing controls should be maintained and audited, and additional security processes may not be required. |

The table of risk acceptability levels is shown under three headings: risk index, risk category, and action.

In the study, when calculating the risk score in the 5x5 L-Decision Matrix analysis, likelihood values (A, B, C, D, E) were converted into numerical form (1, 2, 3, 4, 5). For each criterion, the overall average was taken, and the results were rounded to the nearest numerical value and converted back to their letter equivalents. Severity values were taken as the general average, and the results were also rounded to the nearest numerical value. For example "Implementation of the work in full compliance with the projects" which coded a1 and twenty people evaluated it, the average likelihood score was 2.65 and the average severity score was 3.65. The average likelihood score is 2.65, which corresponds to level C according to Table 3, the average severity score is 3.65, which corresponds to 4 according to Table 4. It means risk score is C4 level according to Table 5 railway risk matrix (5x5 L Type Matrix). The risk average weight multiplied by the numbers 2.65 and 3.65 is 9.67. The evaluation of the criteria that cause railway accidents according to the L-Decision Matrix of 20 experts and the risk obtained according to this evaluation are given in APENDIX-1.

In the study, the criteria that may cause railway accidents were examined in five separate groups and the AHP method was applied separately for each group. In addition, AHP was applied separately for risk, severity and likelihood for these five groups. In the application of the AHP method, the evaluations made by experts according to Saaty's importance scale. In the evaluations, the L-Decision Matrix is based on the values of "1,2,3,4,5", and the AHP technique is based on "1,2,3,...., 9" values. In this study, the AHP technique was applied with reference to the values given in the L-Decision Matrix. For example, the value "1" in the L-Decision Matrix is taken as "1" for AHP, and the value "5" in the L-Decision Matrix is taken as "9" for AHP. Other values are also proportioned between this scale. A pairwise comparison matrix is applied with the evaluations obtained. Then, AHP was applied after taking the geometric mean of the obtained values for each criterion. Lettering and numbering were made taking into account the obtained criterion weights. An example of the application stages of the AHP method in this study is given in APENDIX-2.

## 4. RISK ANALYSIS AND EVALUATION FOR TÜRKİYE

In this study, which was prepared to ensure safe transportation in the railway transportation system in Türkiye, statistical data was obtained from the relevant institutions, the criteria that caused accidents on the railway were determined according to the literature and expert opinion, and these risks were evaluated by experts in the field. According to this evaluation, the criteria were ranked by applying the L-Decision Matrix and AHP methods. The study flow chart is shown in Figure 7.

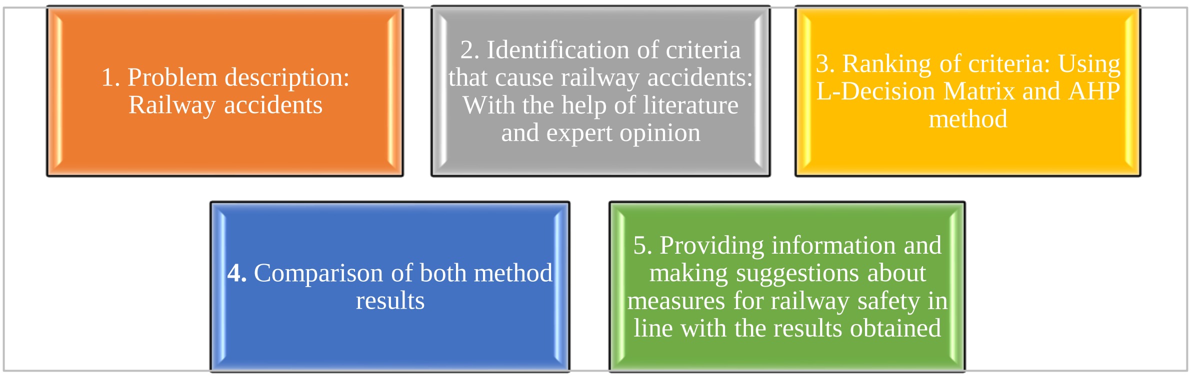


**Figure 7.** Railway risk analysis flow chart

The criteria that may cause railway accidents were determined by taking into consideration TCDD's accident investigation and investigation manuals [41], TCDD's and Minister of Transport of Türkiye's published and unpublished corporate documents, training manuals such as Education Catalog Manuals 2024 [42], Transport Safety Investigation Center of Türkiye's accident investigation reports between 2015 and 2022 [43] and participant suggestions, and literature review. The determined 58 criteria are examined under five headings. Figure 8 shows the determined criteria in the study.

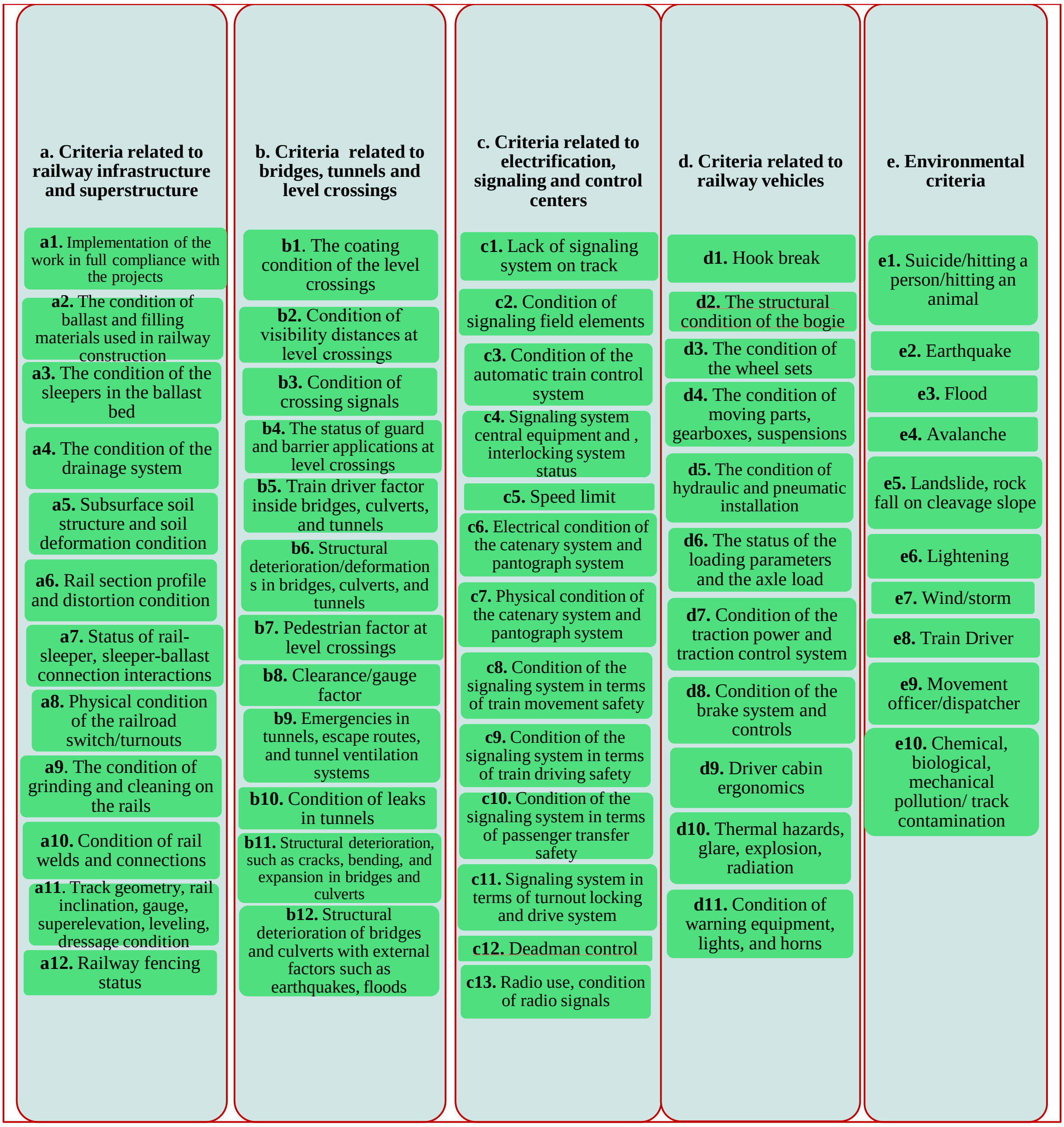


**Figure 8.** Determined Factors (Criteria) Related to Railway Accidents

In the study, the five groups in which the 58 criteria causing railway accidents are classified are "Criteria related to railway infrastructure and superstructure", "Criteria related to bridges, tunnels and level crossings", "Criteria related to electrification, signaling and control centers", "Criteria related to railway vehicles" and "Environmental criteria". In the study, each criterion was evaluated separately by the experts and the relationship between the criteria was not taken into consideration according to the L-Decision Matrix. The weight of the groups relative to each other in railway accidents was not analyzed and each group was considered to have equal weight.

Similarly, in AHP, Although the relationship of each criterion in each group is evaluated, the relative status of the groups as the main criterion is not taken into account. For example, the relative impact of the "Criteria related to railway infrastructure and superstructure" and "Criteria related to bridges, tunnels and level crossings" groups on railway accidents was not examined in the study. However, the relationship of each criterion with other criteria within its group was analyzed separately.

## 5. FINDINGS AND RECOMMENDATIONS

The risk results obtained according to the methods used in the study are listed below. Tables 8 and 9 show the likelihood, severity, and risk results of the AHP and L-Decision Matrix method used in the study, respectively. Table 10 shows the results obtained in the study according to risk index and categories.

**Table 8.** Likelihood, severity, and risk results of L-Decision Matrix according to importance weight of criteria

| AHP Method | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criteria** | **a1** | **a2** | **a3** | **a4** | **a5** | **a6** | **a7** | **a8** | **a9** | **a10** | **a11** | **a12** | **-** |
| Likelihood Importance Weight | 0,0693 | 0,0693 | 0,0693 | 0,0693 | 0,0693 | 0,0693 | 0,0693 | 0,1325 | 0,0370 | 0,0693 | 0,0693 | **0,2068** | - |
| Likelihood Class | D | D | D | D | D | D | D | C | E | D | C | B | - |
| Severity Importance Weight | 0,0744 | **0,1455** | **0,1455** | 0,0744 | 0,0744 | 0,0744 | 0,0744 | 0,0744 | 0,0392 | 0,0744 | 0,0744 | 0,0744 | - |
| Severity Score | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | - |
| Risk Importance Weight (p) | 0,0797 | **0,1357** | 0,0797 | 0,0451 | 0,0451 | 0,0451 | 0,0451 | 0,0797 | 0,0206 | 0,0797 | **0,1357** | 0,0797 | - |
| Risk Index | D3 | D4 | D4 | D3 | D3 | D3 | D3 | C3 | E2 | D3 | C3 | B3 | - |
| **Criteria** | **b1** | **b2** | **b3** | **b4** | **b5** | **b6** | **b7** | **b8** | **b9** | **b10** | **b11** | **b12** | **-** |
| Likelihood Importance Weight | 0,1346 | 0,0779 | 0,0779 | 0,1346 | 0,0779 | 0,0423 | **0,2082** | 0,0423 | 0,0423 | 0,0779 | 0,0423 | 0,0423 | - |
| Likelihood Class | C | D | D | C | D | E | B | E | E | D | E | E | - |
| Severity Importance Weight | 0,0650 | **0,1224** | 0,0650 | **0,1224** | 0,0650 | **0,1224** | **0,1224** | 0,0379 | 0,0650 | 0,0254 | 0,0650 | **0,1224** | - |
| Severity Score | 3 | 4 | 3 | 4 | 3 | 4 | 4 | 2 | 3 | 1 | 3 | 4 | - |
| Risk Importance Weight (p) | 0,0639 | 0,1034 | 0,1034 | 0,1553 | 0,0639 | 0,0639 | **0,2835** | 0,0240 | 0,0382 | 0,0240 | 0,0382 | 0,0382 | - |
| Risk Index | C3 | D4 | D3 | C4 | D3 | E4 | B4 | E2 | E3 | D1 | E3 | E4 | - |
| **Criteria** | **c1** | **c2** | **c3** | **c4** | **c5** | **c6** | **c7** | **c8** | **c9** | **c10** | **c11** | **c12** | **c13** |
| Likelihood Importance Weight | **0,0952** | **0,0952** | **0,0952** | **0,0952** | **0,0952** | 0,0476 | 0,0476 | 0,0476 | 0,0952 | 0,0476 | **0,0952** | 0,0476 | **0,0952** |
| Likelihood Class | C | C | C | C | C | D | D | D | D | D | C | D | C |
| Severity Importance Weight | 0,0410 | 0,0731 | 0,0731 | 0,0731 | **0,1295** | 0,0410 | 0,0410 | **0,1295** | **0,1295** | 0,0410 | **0,1295** | 0,0731 | 0,0257 |
| Severity Score | 3 | 4 | 4 | 4 | 5 | 3 | 3 | 5 | 5 | 3 | 5 | 4 | 2 |
| Risk Importance Weight (p) | 0,0440 | 0,1305 | 0,0777 | 0,1305 | **0,1986** | 0,0440 | 0,0267 | 0,0777 | 0,0777 | 0,0267 | 0,0777 | 0,0440 | 0,0440 |
| Risk Index | C3 | C4 | C4 | C4 | C5 | D3 | D3 | D5 | D5 | D3 | C5 | D4 | C2 |
| **Criteria** | **d1** | **d2** | **d3** | **d4** | **d5** | **d6** | **d7** | **d8** | **d9** | **d10** | **d11** | **-** | **-** |
| Likelihood Importance Weight | 0,0833 | 0,0833 | 0,0833 | 0,0833 | 0,0833 | 0,0833 | **0,1667** | 0,0833 | 0,0833 | 0,0833 | 0,0833 | - | - |
| Likelihood Class | D | D | D | D | D | D | C | D | D | D | D | - | - |
| Severity Importance Weight | 0,0985 | **0,1731** | **0,1731** | 0,0985 | 0,0519 | 0,0985 | 0,0519 | 0,0985 | 0,0519 | 0,0519 | 0,0519 | - | - |
| Severity Score | 3 | 4 | 4 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 2 | - | - |
| Risk Importance Weight (p) | 0,1021 | **0,1760** | **0,1760** | 0,1021 | 0,0570 | 0,1021 | 0,0570 | 0,1021 | 0,0343 | 0,0343 | 0,0570 | - | - |
| Risk Index | D3 | D4 | D4 | D3 | D2 | D3 | C2 | D3 | D2 | D2 | D2 | - | - |
| **Criteria** | **e1** | **e2** | **e3** | **e4** | **e5** | **e6** | **e7** | **e8** | **e9** | **e10** | **-** | **-** | **-** |
| Likelihood Importance Weight | **0,1538** | 0,0769 | 0,0769 | 0,0769 | 0,0769 | 0,0769 | 0,0769 | **0,1538** | **0,1538** | 0,0769 | - | - | - |
| Likelihood Class | C | D | D | D | D | D | D | C | C | D | - | - | - |
| Severity Importance Weight | **0,1828** | 0,1022 | 0,1022 | 0,1022 | 0,1022 | 0,0589 | 0,0381 | **0,1828** | 0,1022 | 0,0265 | - | - | - |
| Severity Score | 5 | 4 | 4 | 4 | 4 | 3 | 2 | 5 | 4 | 1 | - | - | - |
| Risk Importance Weight (p) | **0,2120** | 0,0865 | 0,1355 | 0,0535 | 0,0535 | 0,0535 | 0,0342 | **0,2120** | 0,1355 | 0,0239 | - | - | - |
| Risk Index | C5 | D4 | C4 | D4 | D4 | D3 | D2 | C5 | C4 | D1 | - | - | - |

**Table 9.** Likelihood, severity, and risk results of L-Decision Matrix according to average weight of criteria

| **L-Decision Matrix Method** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criteria** | **a1** | **a2** | **a3** | **a4** | **a5** | **a6** | **a7** | **a8** | **a9** | **a10** | **a11** | **a12** | **-** |
| Likelihood Average Weight | 2,65 | 2,50 | 2,47 | 2,37 | 2,26 | 2,25 | 2,35 | 2,60 | 1,95 | 2,45 | 2,55 | **3,45** | - |
| Likelihood Class | C | C | D | D | D | D | D | C | D | D | C | C | - |
| Severity Average Weight | 3,65 | 3,80 | **3,89** | 3,37 | 3,37 | 3,25 | 3,4 | 3,55 | 2,80 | 3,55 | 3,75 | 3,55 | - |
| Severity Score | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | - |
| Risk Average Weight (p) | 9,67 | 9,50 | 9,63 | 7,98 | 7,62 | 7,31 | 7,99 | 9,23 | 5,46 | 8,70 | 9,56 | **12,25** | - |
| Risk Index | C4 | C4 | D4 | D3 | D3 | D3 | D3 | C4 | D3 | D4 | C4 | C4 | - |
| **Criteria** | **b1** | **b2** | **b3** | **b4** | **b5** | **b6** | **b7** | **b8** | **b9** | **b10** | **b11** | **b12** | **-** |
| Likelihood Average Weight | 2,74 | 2,68 | 2,80 | 3,00 | 2,47 | 1,95 | **3,68** | 1,70 | 1,80 | 2,15 | 1,68 | 1,74 | - |
| Likelihood Class | C | C | C | C | D | D | B | D | D | D | D | D | - |
| Severity Average Weight | 3,37 | 3,84 | 3,70 | 3,79 | 3,42 | **4,11** | **4,11** | 2,80 | 3,85 | 2,70 | 3,68 | 3,95 | - |
| Severity Score | 3 | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | - |
| Risk Average Weight (p) | 9,22 | 10,31 | 10,36 | 11,37 | 8,46 | 7,99 | **15,12** | 4,76 | 6,93 | 5,81 | 6,2 | 6,86 | - |
| Risk Index | C3 | C4 | C4 | C4 | D3 | D4 | B4 | D3 | D3 | D3 | D3 | D3 | - |
| **Criteria** | **c1** | **c2** | **c3** | **c4** | **c5** | **c6** | **c7** | **c8** | **c9** | **c10** | **c11** | **c12** | **c13** |
| Likelihood Average Weight | 2,32 | 2,42 | 2,26 | **2,47** | **2,47** | 2,11 | 1,95 | 2,05 | 2,16 | 1,95 | 2,11 | 1,82 | 2,39 |
| Likelihood Class | D | D | D | D | D | D | D | D | D | D | D | D | D |
| Severity Average Weight | 3,74 | 4,11 | 4,21 | 4,26 | **4,74** | 3,84 | 3,26 | 4,26 | 4,37 | 3,63 | 4,37 | 4,24 | 3,28 |
| Severity Score | 4 | 4 | 4 | 4 | 5 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 3 |
| Risk Average Weight (p) | 8,65 | 9,94 | 9,53 | 10,55 | **11,72** | 8,09 | 6,35 | 8,75 | 9,43 | 7,07 | 9,2 | 7,72 | 7,83 |
| Risk Index | D4 | D4 | D4 | D4 | D5 | D4 | D3 | D4 | D4 | D4 | D4 | D4 | D3 |
| **Criteria** | **d1** | **d2** | **d3** | **d4** | **d5** | **d6** | **d7** | **d8** | **d9** | **d10** | **d11** | **-** | **-** |
| Likelihood Average Weight | 2,06 | 1,95 | 1,89 | 1,89 | 1,94 | 1,84 | **2,21** | 2,05 | 1,79 | 1,95 | 2,11 | - | - |
| Likelihood Class | D | D | D | D | D | D | D | D | D | D | D | - | - |
| Severity Average Weight | 3,65 | 4,00 | 3,83 | 3,78 | 3,28 | 3,68 | 2,84 | 3,47 | 2,84 | 3,11 | 3,32 | - | - |
| Severity Score | 4 | **4** | 4 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | - | - |
| Risk Average Weight (p) | 7,51 | **7,79** | 7,24 | 7,14 | 6,37 | 6,79 | 6,28 | 7,13 | 5,09 | 6,05 | 6,98 | - | - |
| Risk Index | D4 | D4 | D4 | D4 | D3 | D4 | D3 | D3 | D3 | D3 | D3 | - | - |
| **Criteria** | **e1** | **e2** | **e3** | **e4** | **e5** | **e6** | **e7** | **e8** | **e9** | **e10** | **-** | **-** | **-** |
| Likelihood Average Weight | 2,16 | 2,00 | 2,00 | 1,68 | 1,89 | 1,89 | 1,89 | **2,21** | 2,11 | 1,76 | - | - | - |
| Likelihood Class | D | D | D | D | D | D | D | D | D | D | - | - | - |
| Severity Average Weight | **4,32** | 3,89 | 3,95 | 3,89 | 3,89 | 3,58 | 3,05 | 4,26 | 3,83 | 2,41 | - | - | - |
| Severity Score | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 2 | - | - | - |
| Risk Average Weight (p) | 9,31 | 7,79 | 7,89 | 6,56 | 7,38 | 6,78 | 5,78 | **9,42** | 8,09 | 4,26 | - | - | - |
| Risk Index | D4 | D4 | D4 | D4 | D4 | D4 | D3 | D4 | D4 | D2 | - | - | - |

In Table 9, “Likelihood Average Weight” is the sum of the likelihood scores given by the participants divided by the number of participants; “The Average of Severity Weight” is the sum of the severity scores given by the participants divided by the number of participants; “Significant Weight of Risk” is the multiplication result of these two figures for L-Decision Matrix.

In Tables 8 and 9, the results for both methods are given separately. The results obtained for both methods are given in Table 10.

**Table 10.** Risk analysis result

| Risk Index | Risk Category | Criteria Codes (L-Decision Matrix Method) | Criteria Codes (AHP Method) |
|---|---|---|---|
| A4, A5, B5 | Unacceptable Risks | | |
| A3, B4, C5 | High-Grade Risks | b7 | b7, c5, c11, e1 and e8 |
| A2, B2, B3, C3, C4, D4, D5, E5 | Moderate Risks | a1, a2, a3, a8, a10, a11, a12, b1, b2, b3, b4, b6, b9, b11, b12, c1, c2, c3, c4, c5, c6, c8, c9, c10, c11, c12, d1, d2, d3, d4, d6, e1, e2, e3, e4, e5, e6, e8 and e9. | a2, a3, a8, a11, a12, b1, b2, c1, c2, c3, c4, c8, c9, c12, d2, d3, e2, e3, e4, e5 and c4 |
| B4, A1, B1, C1, C2, D1, D2, D3, E1, E2, E3, E4 | Low-Grade Risks | a4, a5, a6, a7, a9, b5, b8, b10, c7, c13, d5, d7, d8, d9, d10, d11, d12, e7 and e10. | a1, a4, a5, a6,a7,a9, a10, b3, b5, b6, b8, b9, b10, b11, b12, c6, c7, c10, c13, d1, d4, d5, d6, d7, d8, d9, d10, d11, e6, e7 and e10 |

As a result of the L-Decision Matrix (5x5) study, the highest risk scores were determined as "Uncontrolled entrances to level crossings by pedestrians" with code b7. The results were also compared with the AHP method, and in addition to the b7 risk obtained in the L-Decision Matrix at the highest risk scores according to the AHP method, c5, c11, e1 and e8 risks were also included in the high-grade risks category.

The high-grade risks category obtained in the AHP and L Decision Matrix are given in Table 11 below, together with the possible results related to the identified risk definitions and mitigation activities. Also, risk definitions and mitigation activities belong to "Railway fencing status" with code a12, "Condition of signaling field elements" with code c2, "Condition of the automatic train control system" with code c3, "Signaling system central equipment and, interlocking system status" with code c4, "Condition of the signaling system in terms of train movement safety" with code c8 and "Condition of the signaling system in terms of train driving safety" with code c9 are given in Table 11, because it is considered important according to experts.

**Table 11.** Risks related to railways and recommended risk reduction activities

| Criterion Code | Criteria | Possible Consequences | Risk Reduction/Prevention Activities |
|---|---|---|---|
| a12 | Condition of railway fencings | Injury, Death, Property Damage | Although railway fencings are not applicable along the track, fence/wall enclosures should be taken along the station and residential areas. Even illegal and uncontrolled entrances should be prevented. The condition of the railway fence applications should be checked regularly. The drivers' field of vision should be clear. Elevated lines can be built; ecological bridges can be built; law enforcement agencies should tighten patrols. |
| b7 | Pedestrian behaviour at level crossings | Injury, Death, Property Damage, Derailment, Collision | One of the precursors that cause the most accidents at level crossings is uncontrolled entrances on the line. The public should be informed about the issue, and social awareness should be developed. Traffic signs and crossing signals are placed. Active protection measures should be taken for pedestrians, physical speed breakers (manual opening doors, maze entrances, active protected doors) should be applied, separate sections should be created for pedestrians at level crossings, barriers must completely block the passage of pedestrians, they must not be short. |
| c2 | Inability to determine the location and understand the line's occupation due to the lack or failure of signaling system field elements, rail circuits, signal booths and signals, relays, balises, and axle meters in the line infrastructure (Condition of signaling field elements) | Injury, Death, Property Damage, Derailment, Collision | They must be in sufficient numbers; they must be regularly and periodically maintained |
| c3 | Failure or malfunction of the appropriate train protection system (automatic train stopping-ATS/automatic train protection- ATP) to be operated by the train on the track (Condition of the automatic train control system) | Injury, Death, Property Damage, Derailment, Collision | There should be periodic checks and maintenance follow-up at regular intervals. At the first exit station, train movement should not be allowed if necessary, depending on the type of fault. |
| c4 | Not opening and closing the switches automatically and completely, not being able to organize a safe route due to system malfunctions, organizing the wrong route, not ensuring continuity of radio communication, and not paying attention to incoming notifications (Signaling system central equipment and interlocking system status). | Injury, Death, Property damage, Derailment, Collision | Tracking systems should be installed in monitoring centers. Staff should be given the necessary training, and periodic checks of the system should be made. |
| c5 | High speed | Injury, Death, Property damage, Derailment, Collision | Machinists must be ensured to comply with the speed limits along the routes and must be monitored from monitoring centers. |
| c8 | Inability to command and control the route created for safe driving and inability to control the speed with automatic systems (Condition of the signaling system in terms of train movement safety). | Injury, Death, Property damage, Derailment, Collision | Primary or advanced signaling systems such as IXL, CBTC, DRS, ATS, and ETCS should be installed. |
| c9 | High speed by train driver | Injury, Death, Property damage, Derailment, Collision | Machinists must be ensured to comply with livre speeds along the routes. Automatic train automation systems should be installed for driving safety. |
| c11 | Locking and drive system malfunctions in turnouts, system errors, sending wrong signals, and incorrect route determination (Signaling system in terms of turnout locking and drive system) | Injury, Death, Property damage, Derailment, Collision | Periodic maintenance should be performed. Personnel training should be provided periodically. |
| e1 | Suicide/hitting a person/hitting an animal | Injury, Death, Property damage, Derailment, Collision | Speed limits appropriate to the visibility of drivers should be set; the track should be isolated from the environment; public awareness should be raised. Obstacle recognition sensors can be used. |

| | | | |
|---|---|---|---|
| e8 | Train driver | Injury, Death, Property damage, Derailment, Collision | Train drivers should receive regular training, practice in training simulators, psycho-technical tests should be organized to asses their psychological and physical competence, adequate rest periods should be provided. |

## 6.CONCLUSION

Turkish railways will be a more modern, efficient, and competitive sector in the future if the right policies and investments are implemented. For healthy and sustainable railway transportation, security will always remain the most critical issue. In this study carried out to ensure railway safety, the L-Decision Matrix and AHP method, were used to examine the status of the risks determined after the evaluation made by benefiting from the knowledge, experience, and opinions of experts.

The number of railway accidents and deaths in Türkiye between 2002 and 2021 tend to decrease. Between the mentioned years, the number of accidents per million train-km of mobility decreased by 86% from 12.23 accidents to 1.65 accidents. The number of deaths decreased by 79%, from 3.3 deaths to 0.7 deaths. Comparing the data for the period between 2010 and 2020, when the safety culture in Türkiye started to increase with the development and modernization of legislation and modernization efforts and was more successful compared to the previous years, the highest values per million train-km movement in Türkiye were 2.79 accidents and 1.45 fatalities.

While level crossing accidents and personal collisions seemed to be higher than other types in the early 2000s, derailment accidents have been higher than other types in recent years. When the types of accidents between EU countries and Türkiye are compared between 2010 and 2020, it is noteworthy that the rate of derailment accidents in Türkiye is approximately 4.5 times higher than the EU average.

When the risk analyses were compared according to the risk average weight score, it was observed that the "Uncontrolled entrances of pedestrians to level crossings" with the factor code b7, L-Decision Matrix p = 15.12 (0 - 25) and AHP method p = 0.28 (0 - 1) b7 is in the high-grade risk category. In addition, in the AHP analysis, factors with codes c5, c11, e1 and e8 were also found to be in the high-grade risk category. AHP analysis was found to give more precise results. Pedestrian-train interactions have emerged as the parameters that cause the most accidents, and the statistics seem to confirm these results.

Precautions regarding the hazards detected in the high-grade risk category are explained in Table 11. It is essential to take a multi-pronged approach to accident prevention at level crossings. Working in collaboration with infrastructure improvements, education, legislation, and technological solutions can improve safety and prevent accidents at level crossings. In order to prevent accidents at level crossings, the primary thing to do is to separate the roadway and railway intersections as much as possible with the help of upper and lower crossings. At intersections that cannot be separated from each other, level crossings should be made as controlled as possible. Crossing routes, especially for pedestrians, should be separated from the railways. At level crossings where roads intersect, crossings should be made relatively difficult to ensure pedestrians are aware of trains. For example, physical speed breakers (manual opening doors, maze entrances, active protected doors) should be applied; separate sections should be created for pedestrians at level crossings; barriers must completely block the passage of pedestrians, and they must not be short.

Signaling system and high speeds are also high grade risk according to AHP on table 10. Train drivers must be ensured to comply with the speed limits along the routes and must be monitored from monitoring centers. Personnel training should be provided periodically. Periodic maintenance should be performed. On the other hand it is seen that signaling systems in Türkiye are made in parts and by different companies with different software and hardware. This situation causes incompatibilities in software, hardware, and integration. Therefore, when establishing signaling systems, the integration and operation difficulties of different systems should be taken into account, and studies should be carried out to reduce this system diversity, for example, by implementing domestic signaling systems.

Yet another high grade risks came from train drivers' themselves and suicide/hitting a person/hitting an animal. Train drivers should receive regular training, practice in training simulators, psycho-technical tests should be organized to asses their psychological and physical competence, adequate rest periods should be provided. In order to prevent suicide/hitting people/hitting animals, train drivers should receive regular training, practice in training simulators, psychotechnical tests should be organized to evaluate their psychological and physical competencies, adequate rest periods should be provided, speed limits appropriate to the visibility of the drivers should be determined, the track should be isolated from the environment, public awareness should be raised, obstacle recognition sensors should be used.

As a continuation of this study, similar risk analysis studies should be carried out at periodic intervals; developments should be monitored; initiatives to minimize possible risks by taking advantage of rapid measures and new technological developments should be followed up to date. Further studies should be conducted in specifically identified areas.

## CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

## CREDIT AUTHOR STATEMENT

**Burçin Paçacı:**Formal analysis, Writing - original draft, Visualization, Writing – Review & Editing. **Hulusi Aydemir:** Conceptualization, Formal analysis, Writing – Original Draft. **Metin Eser:**Conceptualization, Formal analysis, Resources, Writing – Original Draft, Writing – Review & Editing, Visualization. **Serpil Erol:** Methodology, Formal analysis. **M. Kürşat Çubuk:** Conceptualization, Formal analysis, Writing – Original Draft.

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# APENDIX-1

| | | 1. person | | 2. person | | 3. person | | 4. person | | 5. person | | 6. person | | 7. person | | 8. person | | 9. person | | 10. person | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity |
| A1 | Implementation of the work in full compliance with the projects | 5 | 5 | 1 | 1 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 5 | 3 | 5 | 3 | 3 | 2 | 2 |
| A2 | The condition of ballast and filling materials used in railway construction | 3 | 5 | 2 | 4 | 3 | 3 | 3 | 4 | 2 | 4 | 2 | 4 | 3 | 4 | 4 | 5 | 3 | 3 | 3 | 4 |
| A3 | The condition of the sleepers in the ballast bed | 3 | 5 | 2 | 4 | 3 | 3 | 2 | 5 | 4 | 4 | 2 | 2 | 3 | 4 | 3 | 5 | 3 | 5 | 2 | 2 |
| A4 | The condition of the drainage system | 3 | 5 | 2 | 4 | 3 | 2 | 4 | 2 | 3 | 4 | 3 | 3 | 2 | 4 | 2 | 3 | 2 | 2 | 3 | 2 |
| A5 | Subsurface soil structure and soil deformation condition | 3 | 5 | 1 | 4 | 3 | 2 | 1 | 5 | 4 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 2 |
| A6 | Rail section profile and distortion condition | 2 | 3 | 2 | 2 | 3 | 2 | 1 | 4 | 3 | 4 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 2 |
| A7 | Status of rail-sleeper, sleeper-ballast connection interactions | 3 | 4 | 1 | 3 | 3 | 3 | 2 | 4 | 3 | 4 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 3 | 3 | 3 |
| A8 | Physical condition of the railroad switch/turnouts | 3 | 3 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 5 | 3 | 5 | 3 | 4 | 3 | 3 |
| A9 | Condition of grinding and cleaning of rails | 1 | 4 | 1 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 1 |
| A10 | Condition of rail welds and connections | 2 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | 3 | 4 | 2 | 2 | 3 | 2 |
| A11 | Track geometry, rail inclination, gauge, superelevation, leveling, dressage, condition | 2 | 5 | 2 | 3 | 2 | 2 | 2 | 3 | 3 | 4 | 2 | 4 | 3 | 4 | 3 | 5 | 3 | 5 | 2 | 4 |
| A12 | Enclosure status | 2 | 3 | 5 | 4 | 1 | 1 | 5 | 4 | 2 | 4 | 2 | 3 | 4 | 3 | 3 | 5 | 4 | 5 | 2 | 3 |
| B1 | Coating condition of level crossings | 3 | 4 | 1 | 1 | 1 | 2 | 3 | 4 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 5 | 2 | 3 |
| B2 | Condition of Visibility Distances at level crossings | 2 | 4 | 2 | 4 | 1 | 3 | 1 | 5 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 5 |
| B3 | The status of traffic sign applications at level crossings | 2 | 4 | 1 | 4 | 1 | 4 | 1 | 5 | 2 | 2 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 4 |
| B4 | Status of guards and barriers at level crossings | 2 | 4 | 1 | 4 | 1 | 4 | 3 | 4 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | | | 2 | 4 |
| B5 | Train driver factor inside bridges, culverts, tunnels | 2 | 4 | 1 | 2 | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 |
| B6 | Structural deterioration/deformations in bridges, culverts and tunnels | 2 | 2 | 1 | 4 | 1 | 1 | 1 | 5 | 3 | 3 | 1 | 5 | 1 | 5 | 3 | 5 | 3 | 3 | 1 | 5 |
| B7 | Pedestrian factor at level crossings | 3 | 5 | 2 | 4 | 1 | 5 | 5 | 4 | 3 | 4 | 4 | 3 | 5 | 3 | 3 | 2 | 2 | 2 | 3 | 5 |
| B8 | Clearence/gauge factor | 1 | 5 | 1 | 1 | 1 | 2 | 1 | 5 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 2 | 2 | 2 | 1 | 1 |
| B9 | Emergency situations in tunnels, escape routes and tunnel ventilation systems | 1 | 5 | 1 | 1 | 1 | 4 | 1 | 5 | 2 | 2 | 1 | 5 | 2 | 4 | 2 | 5 | 2 | 2 | 1 | 5 |
| B10 | Condition of leaks in tunnels | 2 | 5 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 1 |
| B11 | Structural deterioration such as cracks, bending, expansion in bridges and culverts | 2 | 5 | 1 | 1 | 1 | 3 | 1 | 5 | 2 | 2 | 2 | 3 | 2 | 5 | 2 | 3 | 2 | 2 | 1 | 5 |
| B12 | Structural deterioration of bridges and culverts due to external factors such as earthquakes and floods | 2 | 5 | 1 | 4 | 1 | 4 | 1 | 5 | 2 | 2 | 2 | 4 | 2 | 5 | 2 | 2 | 3 | 3 | 1 | 5 |
| C1 | Lack of signalization system on the lines | 2 | 5 | 1 | 1 | 1 | 1 | 3 | 4 | 2 | 5 | 1 | 2 | 3 | 4 | 3 | 5 | 2 | 2 | | |
| C2 | Condition of signaling field elements | 2 | 5 | 2 | 4 | 1 | 5 | 4 | 3 | 2 | 5 | 2 | 2 | 3 | 5 | 3 | 5 | 2 | 4 | | |
| C3 | Condition of the automatic train control system | 2 | 5 | 2 | 3 | 1 | 5 | 2 | 3 | 2 | 5 | 1 | 2 | 3 | 5 | 3 | 5 | 4 | 5 | | |
| C4 | Signalization system, interlocking system status | 2 | 5 | 2 | 4 | 1 | 5 | 3 | 3 | 2 | 5 | 1 | 3 | 3 | 5 | 3 | 5 | 4 | 5 | | |
| C5 | Speed limit | 2 | 5 | 2 | 4 | 1 | 5 | 2 | 5 | 2 | 5 | 1 | 4 | 4 | 5 | 2 | 5 | 3 | 5 | | |
| C6 | Electrical condition of the catenary system and pantograph system | 2 | 5 | 1 | 1 | 1 | 5 | 1 | 4 | 2 | 3 | 2 | 3 | 2 | 4 | 2 | 5 | 2 | 4 | | |
| C7 | Physical condition of the catenary system and pantograph system | 2 | 3 | 1 | 4 | 1 | 5 | 1 | 5 | 2 | 2 | 2 | 4 | 2 | 3 | 2 | 2 | 2 | 4 | | |
| C8 | Condition of the signaling system in terms of train movement safety | 2 | 5 | 2 | 4 | 1 | 4 | 3 | 4 | 2 | 5 | 1 | 3 | 2 | 5 | 3 | 5 | 2 | 4 | | |
| C9 | Condition of the signaling system in terms of train driving safety | 2 | 5 | 2 | 4 | 1 | 4 | 2 | 5 | 2 | 5 | 2 | 3 | 4 | 4 | 2 | 5 | 2 | 4 | | |
| C10 | Condition of the signaling system in terms of passenger transfer safety | 2 | 4 | 1 | 1 | 1 | 5 | 4 | 2 | 2 | 5 | 1 | 4 | 2 | 4 | 2 | 4 | 2 | 3 | | |
| C11 | Signaling system in terms of turnout locking and drive system | 2 | 5 | 2 | 4 | 1 | 5 | 1 | 5 | 2 | 5 | 1 | 4 | 2 | 5 | 2 | 5 | 2 | 2 | | |
| C12 | Deadman control | 2 | 5 | 1 | 1 | 1 | 4 | 1 | 5 | 1 | 5 | | | 2 | 5 | 2 | 4 | | | | |
| C13 | Radio use, condition of radios | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 4 | | | 2 | 3 | 2 | 4 | 2 | 5 | 2 | 3 | | |
| D1 | Hook break | 2 | 5 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 3 | | | 2 | 4 | 2 | 3 | | | | |
| D2 | Structural condition of the bogie | 2 | 5 | 1 | 1 | 1 | 4 | 2 | 5 | 1 | 5 | 2 | 4 | 2 | 4 | 2 | 3 | 2 | 4 | | |
| D3 | Condition of the wheelsets | 2 | 5 | 2 | 4 | 2 | 1 | 2 | 4 | 1 | 5 | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 3 | | |
| D4 | Condition of moving parts, gearboxes, suspensions | 2 | 5 | 1 | 1 | 2 | 3 | 2 | 5 | 1 | 3 | 2 | 4 | 2 | 4 | 3 | 5 | 2 | 4 | | |
| D5 | Condition of hydraulic and pneumatic | 2 | 5 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 3 | 2 | 4 | 2 | 3 | 2 | 2 | 2 | 4 | | |
| D6 | Condition of loading parameters and axle load | 2 | 5 | 2 | 4 | 1 | 3 | 2 | 4 | 1 | 3 | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 5 | | |
| D7 | Condition of the traction and traction control system | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 4 | 3 | 3 | 2 | 2 | 2 | 5 | 2 | 3 | | |
| D8 | Condition of the brake system and controls | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 5 | 1 | 3 | 2 | 4 | 2 | 4 | 2 | 5 | 2 | 3 | | |
| D9 | Driver cabin ergonomics | 2 | 5 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 5 | 2 | 2 | 2 | 2 | 2 | 4 | | |
| D10 | Thermal hazards: flash, explosion, radiation | 2 | 5 | 1 | 1 | 1 | 1 | 3 | 4 | 1 | 5 | 1 | 5 | 2 | 2 | 2 | 2 | 2 | 3 | | |
| D11 | Condition of warning equipment, lights and horns | 2 | 5 | 1 | 1 | 1 | 3 | 4 | 4 | 1 | 5 | 3 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | | |
| E1 | Suicide/hitting a person/hitting an animal | 2 | 4 | 2 | 4 | 1 | 5 | 1 | 4 | 2 | 5 | 2 | 5 | 2 | 3 | 2 | 3 | 2 | 5 | | |
| E2 | Earthquake | 3 | 5 | 2 | 4 | 1 | 1 | 1 | 5 | 1 | 5 | 2 | 4 | 2 | 5 | 3 | 5 | 2 | 4 | | |
| E3 | Flood | 3 | 5 | 2 | 4 | 1 | 3 | 1 | 5 | 1 | 5 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | | |
| E4 | Avalanche | 3 | 5 | 2 | 4 | 1 | 1 | 1 | 5 | 1 | 5 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 4 | | |
| E5 | Landslide, rock fall on cleavage slope | 3 | 5 | 2 | 4 | 1 | 1 | 1 | 5 | 1 | 5 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 4 | | |
| E6 | Lightening | 3 | 5 | 1 | 1 | 1 | 4 | 1 | 5 | 1 | 5 | 2 | 2 | 2 | 3 | 2 | 3 | 1 | 3 | | |
| E7 | Wind/storm | 1 | 5 | 1 | 1 | 1 | 1 | 4 | 2 | 1 | 5 | 2 | 2 | 2 | 3 | 2 | 4 | 2 | 4 | | |
| E8 | Train driver | 2 | 5 | 2 | 4 | 1 | 4 | 3 | 4 | 2 | 4 | 1 | 5 | 2 | 5 | 3 | 5 | 2 | 4 | | |
| E9 | Movement officer/dispatcher | 2 | 5 | 2 | 4 | 1 | 3 | 2 | 5 | 2 | 4 | 2 | 2 | 2 | 4 | 2 | 3 | 2 | 3 | | |
| E10 | Chemical, biological mechanical pollution/ track contamination | 2 | 3 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 2 | 2 | 2 | | | | |

| | | 11. person | | 12. person | | 13. person | | 14. person | | 15. person | | 16. person | | 17. person | | 18. person | | 19. person | | 20. person | | Possibility/likelihood | Severity | Risk importance score | | | RISK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | Possibility/likelihood | Severity | ABCDE | 12345 | | | | |
| A1 | Implementation of the work in full compliance with the projects | 4 | 3 | 5 | 5 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 4 | 2 | 5 | 2 | 5 | 2 | 4 | 1 | 5 | 2,65 | 3,65 | 9,67 | C | 4 | C 4 |
| A2 | The condition of ballast and filling materials used in railway construction | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 3 | 4 | 2,50 | 3,80 | 9,50 | C | 4 | C 4 |
| A3 | The condition of the sleepers in the ballast bed | 1 | 2 | 2 | 2 | 3 | 4 | 3 | 4 | 1 | 4 | | | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 2,47 | 3,89 | 9,63 | D | 4 | D 4 |
| A4 | The condition of the drainage system | 2 | 3 | 2 | 2 | 2 | 4 | 2 | 4 | 1 | 4 | | | 2 | 5 | 2 | 5 | 2 | 3 | 3 | 3 | 2,37 | 3,37 | 7,98 | D | 3 | D 3 |
| A5 | Subsurface soil structure and soil deformation condition | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 3 | 1 | 4 | | | 3 | 5 | 3 | 5 | 3 | 3 | 3 | 3 | 2,26 | 3,37 | 7,62 | D | 3 | D 3 |
| A6 | Rail section profile and distortion condition | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 3 | 4 | 2,25 | 3,25 | 7,31 | D | 3 | D 3 |
| A7 | Status of rail-sleeper, sleeper-ballast connection interactions | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 2,35 | 3,40 | 7,99 | D | 3 | D 3 |
| A8 | Physical condition of the railroad switch/turnouts | 3 | 3 | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 4 | 2,60 | 3,55 | 9,23 | C | 4 | C 4 |
| A9 | Condition of grinding and cleaning of rails | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 1 | 2 | 1 | 1 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 1,95 | 2,80 | 5,46 | D | 3 | D 3 |
| A10 | Condition of rail welds and connections | 2 | 3 | 3 | 3 | 2 | 4 | 2 | 4 | 1 | 4 | 3 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 2,45 | 3,55 | 8,70 | D | 4 | D 4 |
| A11 | Track geometry, rail inclination, gauge, superelevation, leveling, dressage, condition | 4 | 4 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 3 | 5 | 3 | 5 | 2 | 5 | 3 | 4 | 2,55 | 3,75 | 9,56 | C | 4 | C 4 |
| A12 | Enclosure status | 4 | 4 | 3 | 2 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 2 | 5 | 5 | 4 | 5 | 5 | 3 | 5 | 3 | 3,45 | 3,55 | 12,25 | C | 4 | C 4 |
| B1 | Coating condition of level crossings | 2 | 3 | 2 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | | | 4 | 5 | 4 | 5 | 4 | 4 | 3 | 3 | 2,74 | 3,37 | 9,22 | C | 3 | C 3 |
| B2 | Condition of Visibility Distances at level crossings | 4 | 4 | 2 | 4 | 3 | 4 | 3 | 4 | 2 | 4 | | | 4 | 5 | 4 | 5 | 4 | 5 | 3 | 4 | 2,68 | 3,84 | 10,31 | C | 4 | C 4 |
| B3 | The status of traffic sign applications at level crossings | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 1 | 4 | 3 | 2 | 4 | 5 | 4 | 5 | 4 | 4 | 5 | 4 | 2,80 | 3,70 | 10,36 | C | 4 | C 4 |
| B4 | Status of guards and barriers at level crossings | 4 | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3 | 2 | 4 | 5 | 4 | 5 | 4 | 4 | 5 | 4 | 3,00 | 3,79 | 11,37 | C | 4 | C 4 |
| B5 | Train driver factor inside bridges, culverts, tunnels | 2 | 3 | 2 | 3 | 3 | 4 | 3 | 4 | 2 | 4 | | | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 4 | 2,47 | 3,42 | 8,46 | D | 3 | D 3 |
| B6 | Structural deterioration/deformations in bridges, culverts and tunnels | 1 | 5 | 2 | 4 | 3 | 4 | 3 | 4 | 2 | 3 | | | 2 | 5 | 2 | 5 | 2 | 5 | 3 | 5 | 1,95 | 4,11 | 7,99 | D | 4 | D 4 |
| B7 | Pedestrian factor at level crossings | 4 | 5 | 3 | 4 | 5 | 5 | 5 | 4 | 2 | 4 | | | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 3,68 | 4,11 | 15,12 | B | 4 | B 4 |
| B8 | Clearence/gauge factor | 1 | 2 | 2 | 2 | 2 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 2 | 4 | 2 | 4 | 2 | 4 | 3 | 3 | 1,70 | 2,80 | 4,76 | D | 3 | D 3 |
| B9 | Emergency situations in tunnels, escape routes and tunnel ventilation systems | 3 | 3 | 2 | 2 | 2 | 3 | 2 | 3 | 1 | 3 | 2 | 5 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 5 | 1,80 | 3,85 | 6,93 | D | 4 | D 4 |
| B10 | Condition of leaks in tunnels | 2 | 2 | 2 | 2 | 3 | 3 | 5 | 3 | 2 | 3 | 2 | 2 | 2 | 4 | 2 | 5 | 2 | 4 | 3 | 4 | 2,15 | 2,70 | 5,81 | D | 3 | D 3 |
| B11 | Structural deterioration such as cracks, bending, expansion in bridges and culverts | 1 | 4 | 1 | 3 | 2 | 3 | 2 | 3 | 1 | 3 | | | 2 | 5 | 2 | 5 | 2 | 5 | 3 | 5 | 1,68 | 3,68 | 6,20 | D | 4 | D 4 |
| B12 | Structural deterioration of bridges and culverts due to external factors such as earthquakes and floods | 1 | 4 | 1 | 4 | 2 | 2 | 2 | 2 | 1 | 4 | | | 2 | 5 | 2 | 5 | 2 | 5 | 3 | 5 | 1,74 | 3,95 | 6,86 | D | 4 | D 4 |
| C1 | Lack of signalization system on the lines | 4 | 5 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 3 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 5 | 2,32 | 3,74 | 8,65 | D | 4 | D 4 |
| C2 | Condition of signaling field elements | 3 | 4 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 3 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 4 | 2,42 | 4,11 | 9,94 | D | 4 | D 4 |
| C3 | Condition of the automatic train control system | 3 | 4 | 2 | 3 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 2,26 | 4,21 | 9,53 | D | 4 | D 4 |
| C4 | Signalization system, interlocking system status | 3 | 4 | 2 | 4 | 3 | 3 | 3 | 3 | 2 | 5 | 2 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 5 | 2,47 | 4,26 | 10,55 | D | 4 | D 4 |
| C5 | Speed limit | 3 | 4 | 2 | 4 | 3 | 5 | 3 | 5 | 2 | 5 | 1 | 4 | 3 | 5 | 3 | 5 | 3 | 5 | 5 | 5 | 2,47 | 4,74 | 11,72 | D | 5 | D 5 |
| C6 | Electrical condition of the catenary system and pantograph system | 2 | 3 | 1 | 4 | 4 | 5 | 4 | 5 | 2 | 2 | 1 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 3 | 2,11 | 3,84 | 8,09 | D | 4 | D 4 |
| C7 | Physical condition of the catenary system and pantograph system | 1 | 4 | 1 | 4 | 3 | 4 | 3 | 4 | 2 | 3 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 3 | 1,95 | 3,26 | 6,35 | D | 3 | D 3 |
| C8 | Condition of the signaling system in terms of train movement safety | 3 | 3 | 1 | 4 | 2 | 4 | 2 | 4 | 2 | 5 | 1 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 3 | 2,05 | 4,26 | 8,75 | D | 4 | D 4 |
| C9 | Condition of the signaling system in terms of train driving safety | 3 | 4 | 2 | 4 | 1 | 4 | 1 | 4 | 2 | 5 | 2 | 3 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 5 | 2,16 | 4,37 | 9,43 | D | 4 | D 4 |
| C10 | Condition of the signaling system in terms of passenger transfer safety | 2 | 3 | 1 | 4 | 1 | 3 | 1 | 3 | 2 | 4 | 2 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 3 | 1,95 | 3,63 | 7,07 | D | 4 | D 4 |
| C11 | Signaling system in terms of turnout locking and drive system | 2 | 3 | 2 | 4 | 3 | 4 | 3 | 4 | 2 | 5 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 4 | 2,11 | 4,37 | 9,20 | D | 4 | D 4 |
| C12 | Deadman control | 1 | 3 | 1 | 5 | 2 | 3 | 2 | 3 | 2 | 5 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 5 | 1,82 | 4,24 | 7,72 | D | 4 | D 4 |
| C13 | Radio use, condition of radios | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 5 | 2,39 | 3,28 | 7,83 | D | 3 | D 3 |
| D1 | Hook break | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 4 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 3 | 4 | 2,06 | 3,65 | 7,51 | D | 4 | D 4 |
| D2 | Structural condition of the bogie | 3 | 4 | 1 | 4 | 3 | 3 | 3 | 3 | 2 | 5 | 2 | 3 | 2 | 5 | 2 | 5 | 2 | 5 | 2 | 4 | 1,95 | 4,00 | 7,79 | D | 4 | D 4 |
| D3 | Condition of the wheelsets | 2 | 4 | 1 | 3 | 2 | 4 | 2 | 4 | 2 | 3 | | | 2 | 5 | 2 | 5 | 2 | 5 | 2 | 4 | 1,89 | 3,83 | 7,24 | D | 4 | D 4 |
| D4 | Condition of moving parts, gearboxes, suspensions | 2 | 4 | 1 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | | | 2 | 5 | 2 | 5 | 2 | 5 | 2 | 3 | 1,89 | 3,78 | 7,14 | D | 4 | D 4 |
| D5 | Condition of hydraulic and pneumatic | 1 | 3 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 3 | | | 2 | 5 | 2 | 5 | 2 | 5 | 5 | 3 | 1,94 | 3,28 | 6,37 | D | 3 | D 3 |
| D6 | Condition of loading parameters and axle load | 2 | 4 | 1 | 2 | 2 | 3 | 2 | 3 | 3 | 4 | 1 | 3 | 2 | 5 | 2 | 3 | 2 | 5 | 2 | 4 | 1,84 | 3,68 | 6,79 | D | 4 | D 4 |
| D7 | Condition of the traction and traction control system | 3 | 3 | 2 | 2 | 3 | 4 | 3 | 4 | 2 | 3 | 2 | 1 | 2 | 3 | 2 | 5 | 2 | 3 | 5 | 3 | 2,21 | 2,84 | 6,28 | D | 3 | D 3 |
| D8 | Condition of the brake system and controls | 2 | 4 | 2 | 2 | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 2 | 2 | 5 | 2 | 4 | 2 | 5 | 3 | 4 | 2,05 | 3,47 | 7,13 | D | 3 | D 3 |
| D9 | Driver cabin ergonomics | 2 | 3 | 2 | 2 | 1 | 2 | 1 | 2 | 3 | 3 | 2 | 2 | 2 | 4 | 2 | 5 | 2 | 4 | 3 | 2 | 1,79 | 2,84 | 5,09 | D | 3 | D 3 |
| D10 | Thermal hazards: flash, explosion, radiation | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 3 | 1 | 2 | 2 | 4 | 2 | 5 | 2 | 4 | 5 | 2 | 1,95 | 3,11 | 6,05 | D | 3 | D 3 |
| D11 | Condition of warning equipment, lights and horns | 1 | 2 | 2 | 3 | 2 | 4 | 2 | 4 | 2 | 3 | 3 | 1 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 2,11 | 3,32 | 6,98 | D | 3 | D 3 |
| E1 | Suicide/hitting a person/hitting an animal | 3 | 5 | 2 | 4 | 3 | 4 | 3 | 4 | 2 | 4 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 4 | 4 | 2,16 | 4,32 | 9,31 | D | 4 | D 4 |
| E2 | Earthquake | 1 | 5 | 1 | 4 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 3 | 5 | 5 | 2,00 | 3,89 | 7,79 | D | 4 | D 4 |
| E3 | Flood | 2 | 4 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 4 | 2 | 4 | 2 | 4 | 4 | 5 | 2,00 | 3,95 | 7,89 | D | 4 | D 4 |
| E4 | Avalanche | 1 | 5 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 4 | 2 | 4 | 1 | 5 | 1 | 5 | 1 | 2 | 2 | 5 | 1,68 | 3,89 | 6,56 | D | 4 | D 4 |
| E5 | Landslide, rock fall on cleavage slope | 2 | 4 | 2 | 4 | 2 | 3 | 2 | 3 | 2 | 5 | 2 | 4 | 1 | 5 | 1 | 5 | 1 | 2 | 5 | 5 | 1,89 | 3,89 | 7,38 | D | 4 | D 4 |
| E6 | Lightening | 1 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 3 | 2 | 2 | 2 | 5 | 2 | 5 | 2 | 2 | 5 | 4 | 1,89 | 3,58 | 6,78 | D | 4 | D 4 |
| E7 | Wind/storm | 1 | 4 | 1 | 1 | 2 | 4 | 2 | 4 | 2 | 3 | 1 | 1 | 2 | 4 | 2 | 3 | 2 | 4 | 5 | 3 | 1,89 | 3,05 | 5,78 | D | 3 | D 3 |
| E8 | Train driver | 3 | 4 | 2 | 5 | 2 | 3 | 2 | 3 | 2 | 5 | 2 | 3 | 2 | 5 | 2 | 5 | 2 | 3 | 5 | 5 | 2,21 | 4,26 | 9,42 | D | 4 | D 4 |
| E9 | Movement officer/dispatcher | 3 | 4 | | | 2 | 3 | 2 | 3 | 2 | 5 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 2 | 4 | 5 | 2,11 | 3,83 | 8,09 | D | 4 | D 4 |
| E10 | Chemical, biological mechanical pollution/ track contamination | 1 | 3 | | | 1 | 2 | 1 | 2 | 3 | 3 | 1 | 2 | 2 | 4 | 2 | 4 | 2 | 4 | 3 | 3 | 1,76 | 2,41 | 4,26 | D | 2 | D 2 |

1- The scores of the participants are shown in the table.
2- Participants were not given any response restrictions and were asked to make evaluations based on their own areas of expertise, if possible.
3- Only example of the L-Matrix method is given here.
4- For the L matrix, the probability and severity scores are averaged among themselves and rounded to the nearest number or letter value. Risk importance weight is expressed as the numerical value multiplication of the averages.

## APENDIX-2

Application of the criteria in group “D” according to the AHP technique: “Risk” example

| | d1 | d2 | d3 | d4 | d5 | c6 | d7 | d8 | d9 | d10 | d11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| d1 | 1,0000 | 0,5000 | 0,5000 | 1,0000 | 2,0000 | 1,0000 | 2,0000 | 1,0000 | 3,0000 | 3,0000 | 2,0000 |
| d2 | 2,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 |
| d3 | 2,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 |
| d4 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 |
| d5 | 0,5000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 0,5000 | 1,0000 | 0,5000 | 1,0000 | 1,0000 | 1,0000 |
| d6 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 2,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 |
| d7 | 0,5000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 0,5000 | 1,0000 | 1,0000 | 1,0000 |
| d8 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 2,0000 | 1,0000 | 2,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 |
| d9 | 0,3333 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 0,5000 |
| d10 | 0,3333 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 0,5000 |
| d11 | 0,5000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 1,0000 | 2,0000 | 2,0000 | 1,0000 |
| Totally | 10,1667 | 10,5000 | 10,5000 | 11,0000 | 14,0000 | 10,5000 | 13,0000 | 10,0000 | 14,0000 | 14,0000 | 11,0000 |

| | d1 | d2 | d3 | d4 | d5 | c6 | d7 | d8 | d9 | d10 | d11 | Criteria Weight (wi) (Equation 2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d1 | 0,0984 | 0,0909 | 0,0909 | 0,0984 | 0,1111 | 0,0984 | 0,1111 | 0,0984 | 0,1071 | 0,1071 | 0,1111 | 0,1021 |
| d2 | 0,1967 | 0,1818 | 0,1818 | 0,1967 | 0,1667 | 0,1967 | 0,1667 | 0,1967 | 0,1429 | 0,1429 | 0,1667 | 0,1760 |
| d3 | 0,1967 | 0,1818 | 0,1818 | 0,1967 | 0,1667 | 0,1967 | 0,1667 | 0,1967 | 0,1429 | 0,1429 | 0,1667 | 0,1760 |
| d4 | 0,0984 | 0,0909 | 0,0909 | 0,0984 | 0,1111 | 0,0984 | 0,1111 | 0,0984 | 0,1071 | 0,1071 | 0,1111 | 0,1021 |
| d5 | 0,0492 | 0,0606 | 0,0606 | 0,0492 | 0,0556 | 0,0492 | 0,0556 | 0,0492 | 0,0714 | 0,0714 | 0,0556 | 0,0570 |
| d6 | 0,0984 | 0,0909 | 0,0909 | 0,0984 | 0,1111 | 0,0984 | 0,1111 | 0,0984 | 0,1071 | 0,1071 | 0,1111 | 0,1021 |
| d7 | 0,0492 | 0,0606 | 0,0606 | 0,0492 | 0,0556 | 0,0492 | 0,0556 | 0,0492 | 0,0714 | 0,0714 | 0,0556 | 0,0570 |
| d8 | 0,0984 | 0,0909 | 0,0909 | 0,0984 | 0,1111 | 0,0984 | 0,1111 | 0,0984 | 0,1071 | 0,1071 | 0,1111 | 0,1021 |
| d9 | 0,0328 | 0,0455 | 0,0455 | 0,0328 | 0,0278 | 0,0328 | 0,0278 | 0,0328 | 0,0357 | 0,0357 | 0,0278 | 0,0343 |
| d10 | 0,0328 | 0,0455 | 0,0455 | 0,0328 | 0,0278 | 0,0328 | 0,0278 | 0,0328 | 0,0357 | 0,0357 | 0,0278 | 0,0343 |
| d11 | 0,0492 | 0,0606 | 0,0606 | 0,0492 | 0,0556 | 0,0492 | 0,0556 | 0,0492 | 0,0714 | 0,0714 | 0,0556 | 0,0570 |

| | d1 | d2 | d3 | d4 | d5 | c6 | d7 | d8 | d9 | d10 | d11 | Totally (di) (Equation 3) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d1 | 0,1021 | 0,0880 | 0,0880 | 0,1021 | 0,1141 | 0,1021 | 0,1141 | 0,1021 | 0,1028 | 0,1028 | 0,1141 | 1,1321 |
| d2 | 0,2042 | 0,1760 | 0,1760 | 0,2042 | 0,1711 | 0,2042 | 0,1711 | 0,2042 | 0,1370 | 0,1370 | 0,1711 | 1,9561 |
| d3 | 0,2042 | 0,1760 | 0,1760 | 0,2042 | 0,1711 | 0,2042 | 0,1711 | 0,2042 | 0,1370 | 0,1370 | 0,1711 | 1,9561 |
| d4 | 0,1021 | 0,0880 | 0,0880 | 0,1021 | 0,1141 | 0,1021 | 0,1141 | 0,1021 | 0,1028 | 0,1028 | 0,1141 | 1,1321 |
| d5 | 0,0510 | 0,0587 | 0,0587 | 0,0510 | 0,0570 | 0,0510 | 0,0570 | 0,0510 | 0,0685 | 0,0685 | 0,0570 | 0,6297 |
| d6 | 0,1021 | 0,0880 | 0,0880 | 0,1021 | 0,1141 | 0,1021 | 0,1141 | 0,1021 | 0,1028 | 0,1028 | 0,1141 | 1,1321 |
| d7 | 0,0510 | 0,0587 | 0,0587 | 0,0510 | 0,0570 | 0,0510 | 0,0570 | 0,0510 | 0,0685 | 0,0685 | 0,0570 | 0,6297 |
| d8 | 0,1021 | 0,0880 | 0,0880 | 0,1021 | 0,1141 | 0,1021 | 0,1141 | 0,1021 | 0,1028 | 0,1028 | 0,1141 | 1,1321 |
| d9 | 0,0340 | 0,0440 | 0,0440 | 0,0340 | 0,0285 | 0,0340 | 0,0285 | 0,0340 | 0,0343 | 0,0343 | 0,0285 | 0,3782 |
| d10 | 0,0340 | 0,0440 | 0,0440 | 0,0340 | 0,0285 | 0,0340 | 0,0285 | 0,0340 | 0,0343 | 0,0343 | 0,0285 | 0,3782 |
| d11 | 0,0510 | 0,0587 | 0,0587 | 0,0510 | 0,0570 | 0,0510 | 0,0570 | 0,0510 | 0,0685 | 0,0685 | 0,0570 | 0,6297 |

| | di | wi | di/wi | |
|---|---|---|---|---|
| d1 | 1,1321 | 0,1021 | 11,0906 | λmax= $\frac{\sum_{i=1}^{n}\frac{di}{wi}}{n}$ (Equation 4) |
| d2 | 1,9561 | 0,1760 | 11,1129 | λ =11,0713, n=11 (n=number of criteria) |
| d3 | 1,9561 | 0,1760 | 11,1129 | |
| d4 | 1,1321 | 0,1021 | 11,0906 | |
| d5 | 0,6297 | 0,0570 | 11,0386 | Consistency Ratio (CR)=( λ-n)/((n-1)*RI) (Equation 5) |
| d6 | 1,1321 | 0,1021 | 11,0906 | RI=1,51 for n=11 (Table 3) |
| d7 | 0,6297 | 0,0570 | 11,0386 | CR=(11,0713-11)/(10*1,51)=0,0071<0,1 |
| d8 | 1,1321 | 0,1021 | 11,0906 | |
| d9 | 0,3782 | 0,0343 | 11,0401 | |
| d10 | 0,3782 | 0,0343 | 11,0401 | |
| d11 | 0,6297 | 0,0570 | 11,0386 | |