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Multicriteria Health and Safety Risk Assessments in Highway Construction Projects

Georgios K. Koulinas [1,2,*], Olympia E. Demesouka [1], Panagiotis K. Marhavilas [1], Nikolaos I. Orfanos [2] and Dimitrios E. Koulouriotis [1,2]

[1] Department of Production and Management Engineering, Democritus University of Thrace, Vas. Sofias 12 St., 67132 Xanthi, Greece; marhavil@pme.duth.gr (P.K.M.)
[2] Department of Engineering Project Management, Faculty of Science and Technology, Hellenic Open University, Parodos Aristotelous 18 St., 26335 Patra, Greece
* Correspondence: gkoulina@pme.duth.gr

Abstract: Road building sites are no exception to the fact that construction is one of the most dangerous businesses in the world. There are a number of concerns about the health and safety of the workers at these sites since they combine personnel, machinery, and construction equipment. The purpose of this paper is to determine, analyze, and compare the risks present at road building sites, and how they affect the health and safety of the workers. The study also examines workplace stress and psychosocial risk factors, which may have long-term effects on workers' physical and mental health. To meet the goals of the research, risk evaluations for a specific construction project were carried out using the Analytic Hierarchy Process (AHP). Using the risk categories and risk factor hierarchy, the AHP compares data pairings. The skills, experience, judgments, and value system of the decision-makers were taken into account while deciding the amount of importance to give each criterion. The final risk rankings were established after calculating the overall priority numerically and running the necessary judgment consistency tests. The most significant risks to the health and safety of workers at road construction sites were identified by the study's findings. The study additionally showed that psychosocial risk factors were important contributors to workplace stress and may have a negative impact on employees' health and wellbeing. The results of the present study have important implications for risk management practices in the construction industry. Project managers can implement effective mitigation measures to reduce the likelihood and severity of accidents and injuries by identifying and evaluating the most critical risks associated with road construction sites. The findings also highlight the importance of addressing psychosocial risk factors and workplace stress in improving workers' health and safety outcomes. Overall, this study underscores the need for a comprehensive approach to risk management that considers the diverse and complex factors contributing to construction site hazards.

Keywords: Analytical Hierarchy Process (AHP); risk assessment; safety; road construction project; multicriteria analysis; health

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1. Introduction

Risks and hazards associated with construction projects include exposure to hazardous chemicals, electrical hazards, and falls. Ineffective management of these risks can result in accidents, injuries, and even fatalities. Apart from the obvious human cost, these incidents can cause serious financial losses for the involved companies, including harm to their reputations, legal costs, and more expensive insurance rates. To reduce these dangers, health and safety risk assessments are essential. Enterprises can put procedures in place that assist in preventing mishaps and safeguard workers by recognizing and prioritizing risks. A safe working environment not only benefits the well-being of workers, but it can also lead to improved productivity, motivation, and reduced absenteeism, which can ultimately impact the company's bottom line.

Taking into consideration these obligations, it is perceived that the final duty of the responsible engineer is to make the right decisions (or to make available the decision base for others), ensuring that civil engineering facilities (such as road construction works) are settled in a way which provides the most significant possible profit, and if this benefit cannot be proven, these facilities are not going to be established [1].

To continue, the construction industry is considered to have a relatively extraordinary injury and illness rate in comparison with other industries, while highway construction and its maintenance sector (i.e., inside the construction industry) are the most dangerous ones [2]. According to [3], the statistics indicate that the number of injuries and fatalities on highway construction projects continually rises, primarily due to unsafe driver behavior, such as distracted driving, and the discrete features of highway construction jobs (for instance, nighttime paving). Their safety improvement is accomplished efficiently by proactive methods in association with the utilization of reliable risk data. Furthermore, safety risk quantification is the initial step towards assimilating safety data into design and planning [2].

Highway and road construction are essential for modern transportation infrastructure, but they can also pose significant safety risks. To mitigate these risks, researchers have developed various frameworks and models for project risk assessment in highway construction. Risk assessment is the process of identifying, evaluating, and prioritizing the potential risks associated with a particular project. In the development of roads and highways, risk assessment is a crucial step that aids in identifying potential risks. Risks related to accidents that may be caused by construction equipment and falling from heights during maintenance or repair work might be recognized through such inspections. To protect the safety of the employees during construction, highway projects must take special safety precautions. Risks in this context can include mishaps brought on by machinery and vehicles employed in construction, and crumbling buildings or unsecured objects. Identification of these risks, assessment of the likelihood of their occurrence, and appropriate action to manage and reduce related risks are the goals of risk assessment [4].

In [5], they conducted a literature review and surveyed construction professionals, and 33 risks associated with highway construction projects in the UAE were identified. The priority of each risk was determined by the probability and impact, with the most critical risks being inefficient planning and design quality.

Additionally, in [6] determined the risk values of every single danger source, via an expert questionnaires survey, by the usage of the LEC (likelihood, exposure, and consequence) technique, and they implemented the risk evaluation of the construction of the navigable span bridges by the usage of the WBS-RBS (work breakdown structure-risk breakdown structure) method and the fuzzy analytic hierarchy process.

Recently, in [7] presented a health risk evaluation model that relied on the Monte Carlo simulation to evaluate the carcinogenic and non-carcinogenic risks to construction workers during pavement construction due to volatile organic compounds (VOC) emissions from the asphalt pavement. More precisely, by distribution and sensitivity analyses, they illustrated the factors that pose the highest health risks produced by certain VOCs.

Additionally, in [8] selected the most suitable set of sustainability indicators (Sis), which are critical prior to accomplishing a construction sustainability assessment, to arrange the three sustainability pillars (i.e., economic/ social, environmental) of highway sustainability by a novel decision-making approach. Their suggested framework has accounted for the risk spirit of experts under a triangular intuitionistic fuzzy (TIF) environment to handle the intrinsic ambiguity (or vagueness) which is present during the assessment procedure, whereas, in addition, their approach (and also its applicability) has been implemented via a case study concerning highway construction projects.

In [9], the authors proposed a risk-based inspection (RBI) approach for optimizing construction inspections that relied on criticality. The risk impact (RI) data collected by specialists were used to develop a probabilistic risk assessment model. Additionally, a fuzzy set (FS) and Bayesian belief network (BBN) were merged to generate a fuzzy Bayesian belief network (FBBN) suitable for modeling. The approach results unveiled that more than fifty percent of the bridge deck and earthwork inspections are outstanding RI, whereas hot-mix asphalt (HMA) and Portland cement concrete pavement (PCCP) need more high-RI inspections.

Safety risk evaluations are increasingly using multicriteria approaches. When managing and mitigating risks in complicated and uncertain environments, when conventional risk assessment approaches may not be sufficient, stakeholders can use these decision-making tools to weigh numerous aspects. More specifically, in [2] used the Delphi tool to quantify the safety risks associated with highway construction tasks and created a decision support system for incorporating safety risk information into project schedules to improve preconstruction safety procedures. When determining the relative safety risks of 25 common highway construction tasks, they applied several controls to lessen cognitive bias and chose professionals who met strict requirements.

Additionally, in [10] carried out a risk assessment of a subway tunnel close to a bridge over a highway, identifying safety risk variables and developing a system of risk evaluation indexes. By calculating the relative importance of each component in the index system, they employed the analytical hierarchy approach to evaluate the main causes of risk. In the study of [11], the authors proposed F-ANP for risk analysis in the construction of a highway mountain tunnel, which includes Delphi, ANP, and fuzzy comprehensive evaluation methods. Their methodology was deemed reasonable and practical for use in future projects to ensure construction safety and minimize losses.

In [12], fuzzy AHP was utilized to assess the safety risk of projects, depending on efficient parameters affecting the safety risk of constructions.

Additionally, in [13] was combined the analytic hierarchy process and the fuzzy comprehensive evaluation method, and the AHP-fuzzy comprehensive evaluation method was used to determine the present level of safety risk in road bridge construction. Effective precautions should be implemented in accordance with the various risk levels to prevent dangerous incidents.

Additionally, as [14] stated, the use of the nine areas of PMBOK for risk identification and FAHP for performing evaluations ensures a comprehensive assessment of the hazards and enables project managers to implement suitable measures to mitigate these risks effectively.

Additionally, the recent research of [15] employed typical AHP and real data to assess risks during infrastructure project construction.

A comprehensive survey regarding the application of risk acceptance criteria to risk assessment in occupational health and safety can be found in the study of [16].

The rest of the article is organized as follows: Section 2 describes the general idea of the Analytical Hierarchy Process, Section 3 presents the proposed framework for risks assessments, Section 3 illustrates the application of a highway construction project in Heraklion prefecture, Greece, and Section 4 includes discussing of the findings.

2. Methodology

The Analytical Hierarchy Process (AHP) belongs to the category of multicriteria analysis methods. It was proposed by [17] and is used in many applications. It divides the problem into its component elements, with the decision-makers assessments determining the absolute priorities. AHP permits the application of both qualitative and quantitative criteria, experience and intuition, and the verification of judgmental consistency. Three levels make up the hierarchical model: the top level represents the aim of the decision problem, the bottom level includes potential solutions, and the middle level examines the factors that affect the decision. Lower levels have no bearing on how elements rank at a given level. AHP integrates logic and emotion by fusing math and psychology. The method’s adaptability, thoroughness, and capacity to recognize the interaction between aspects make it valuable. In AHP, the hierarchy structure is essential for defining the caliber of the output. The structure can include more than one level (sub-criteria) to contribute to the satisfaction of each criterion. The degree of detail, size, and hierarchy structure depend on the problem's complexity and the degree of analysis required. The main goal of the problem is at the top level, and subsequent levels may include multiple elements, each of equal importance. As described in [18], the priorities of the criteria emerge based on their contribution to fulfilling the hierarchy's purpose, with sub-criteria and criteria introduced where deep analysis is required. The pairwise comparison of the elements of each level follows, using a numerical scale of nine intensity levels to indicate the relative importance of one element compared to another. After the process is completed, the hierarchy can be reviewed, and the method can be reapplied if there are doubts about the result.

The values of this fundamental scale of AHP [18] express the equivalence of preferences, moderate, strong, very strong, and the strongest preference of one item over another according to the subjective judgment and feeling of the receiver (Table 1). The intermediate values of the scale reflect intermediate states. Experience has shown that this scale of nine levels is reasonable and primarily reflects the gradation of the intensity of relationships between elements. The control of the consistency of the judgments is done at the last stage of the method procedure

Table 1. The scale of the typical AHP method.

Description	Level of Importance
Equal importance	1
Factor i is moderately more important than factor j	3
Factor i is strongly more important than factor j	5
Factor i is very strongly more important than factor j	7
Factor i is extremely more important than factor j	9
Intermediate values	2, 4, 6, and 8

3. The Proposed Framework

On highway construction sites, serious accidents occur during project construction, resulting in severe injury or even death of the workers. During the construction process, the simultaneous participation of man, machines, and, in general, construction site equipment, in combination with the conditions of the natural environment, increases the risk factors related to the health and safety of workers, making road construction sites as workplaces increase occupational risk.

The identification, recognition, and analysis of risks and the assessment of all the parameters that may cause accidents during project construction are performed to constitute an essential point of reference for the management and analysis of risks that threaten workers' health and safety on the site. Risk evaluation is attempted using multicriteria analysis, precisely the Analytical Hierarchy Process (AHP) method.

The purpose is to apply the method to obtain the final ranking of the prevailing risks in terms of their effects on health and safety according to the subjective judgment and the value system of the decision maker. Thus, it is possible to make the appropriate decisions each time the project's contributors for its management regarding the specific risks that have been qualified (e.g., redistribution of the project's financial resources for risks related to the project's security measures).

From the research of data in bibliographic sources for all categories of road construction projects [19] but also from the manager's knowledge and experience, the identification and recognition of risks related to health and safety in every construction phase of a project. Then, a grouping of all the risks throughout the execution of the project is attempted, and finally, nine categories of risks emerge, as shown in Table 2.

Table 2. The risk categories and the specific risks identified in a highway construction project.

Risk Category ID	Risk Category	Risk Factor ID	Risk Factor
R1	Project machinery—Vehicles	R1.1	Collisions/crushes of vehicles and construction machinery
		R1.2	Overturning of vehicles and project machinery
		R1.3	Machinery with moving parts
		R1.4	Machinery failure
		R1.5	Lifting machinery failure
		R1.6	Machinery maintenance
		R1.7	Hand tools
		R1.8	Injury to worker by off-site vehicle
R2	Fall of a worker from a height	R2.1	Falling from working floors at height (bridge or tunnel deck)—accesses
		R2.2	Falls from scaffolding
		R2.3	Falls into ditches or wells
R3	Ground Failures—Collapses	R3.1	Landslide/frontal collapse
		R3.2	Artificial slopes and excavations
		R3.3	Rock or boulder fall
		R3.4	Throwing materials
		R3.5	Material drop after detonation
R4	Work environment and ergonomic factors	R4.1	Risk of slipping due to bad weather conditions
		R4.2	Unsafe work floors and access roads
		R4.3	Injury from arming waits
		R4.4	Contact with shotcrete accelerator
		R4.5	Material use failures and material connections
		R4.6	Musculoskeletal diseases in the joints/spine
R5	Falls—Displacement of Materials/explosions—ejected materials—fragments	R5.1	Transported materials—Unloading
		R5.2	Falling of materials from a height
		R5.3	Falling or throwing materials
		R5.4	Cement detachment from height
		R5.5	Explosives—blasts
		R5.6	Stress failure of materials
		R5.7	Explosive materials
R6	Fire—Burns—Electric shock	R6.1	Flammable materials or gases
		R6.2	Sparks and short circuits
		R6.3	High temperatures
		R6.4	Burn from contact with high temperature materials
		R6.5	Electric shock from high voltage cables
		R6.6	Electric shock when using machinery
R7	Flooding—Groundwater	-	-
R8	Exposure to harmful factors	R8.1	Noise
		R8.2	Body and upper limb tremors
		R8.3	Microclimate and UV radiation
		R8.4	Lighting
		R8.5	Compressed air work
		R8.6	Odors—inhalations from fumes of toxic mixtures and gases
		R8.7	Powder—crystalline silicon
		R8.8	Contact of impurities with the body and eyes
		R8.9	Sanitary facilities
R9	Psychosocial risks and occupational stress	R9.1	Risk of harm to physical health
		R9.2	Risk of mental health damage
		R9.3	Risk of social harm

Assessing the project's safety risk is crucial to efficient construction project management because construction sites are one of the most frequent places for accidents. The suggested framework for risk analysis and evaluation based on the AHP application is shown in Figure 1 below.

Figure 1. The flowchart of the proposed approach.

Before filling up the pairwise comparison matrices for those tasks, the hazards that could occur while carrying out each job are listed. The weights for each risk are obtained using the typical AHP process described by [18], and the hazards are ranked according to their weights, highest to lowest. After identifying the most significant risks, the risk manager can allocate a budget for risk mitigation measures tailored to the most significant risks associated with this specific project.

4. Highway Construction Project Application

The proposed framework was applied to a public construction project. It was concerned with assessing workers' health and safety risks by applying the Analytical Hierarchy Process (AHP) method during highway construction. The project under study is the "Completion of the construction of the Agia Varvara–Apomarma road, 7.82 Km long, which is part of the new alignment of the Heraklion–Moires National Road (EO 97) in the prefecture of Heraklion, Crete, Greece.

The project includes completing works in various locations of the road section that were started in a previous contract and were not completed as severe problems of landslides occurred on the slopes. It also includes new works that emerged after geotechnical investigations and new studies and were deemed necessary in order to complete the project.

After considering the risks of a road construction project, the project manager-engineer is asked to apply the AHP method for their evaluation. Based on his knowledge, experience, and feeling, the manager attempts to classify the risks according to the degree of their impact on the safety and health of the workers for the specific project. From the final result of the local and final priorities, the manager-engineer and the rest of the project planning factors will be able to make appropriate decisions regarding project management.

In this project, the general objective of the problem is to achieve the maximum degree of safety and health for the workers. Consequently, the degree of impact of each risk concerning the objective must be determined. The criteria will be the nine risk categories, and the sub-criteria will be the risks of each category.

Therefore, the hierarchy of the problem consists of three levels:

- The general objective (safety and health of workers) will be placed at the upper level;
- At the second level, we placed the criteria, i.e., the nine categories of risks which will be evaluated in terms of the objective;
- The last level includes the sub-criteria, i.e., the risks of each category (criterion) and which we will evaluate according to the corresponding criterion.

Note that the problem hierarchy does not include the level of alternatives, the last level of a typical AHP problem, because the study's objective is to rank the risks in order of importance. The following Figure 2 shows the hierarchical structure of the problem.

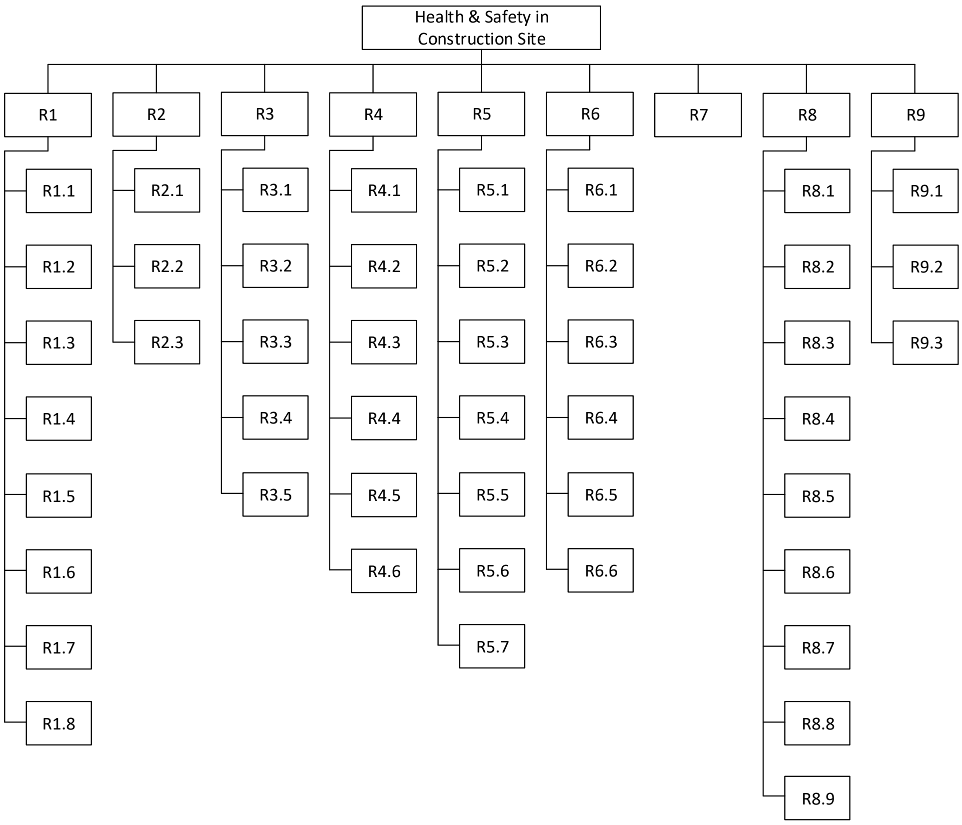

Figure 2. The hierarchy for the project under study.

4.1. Judgements and Solution Extraction

In the project under consideration, the categories of risks (criteria) were compared in terms of the general objective and, on the other hand, the risks of each category (sub-criteria) in terms of the corresponding risk category so that finally, the most important one emerged. During the assessment process, the project manager is asked to judge "how much one category of risk is more important than another in terms of the safety and health of workers on the project site" and "how much a risk of one category is more important than another risk of the same category".

To quantify the superiority priority of one criterion/sub-criterion in relation to another, the fundamental scale of AHP [18] is used, as mentioned.

The priorities are presented directly in the tables after completing the judgment matrices consistency control stage. The λ_{max}, the consistency index ($CI = (\lambda max - n)/(n-1)$), and the consistency ratio ($CR = CI/RI$) have been determined according to [18], where λ_{max} is the major or principal Eigenvalue of the matrix, and n is the order of the matrix. The average random consistency index (RI) is illustrated in Table 3.

Table 3. Random consistency index for different order of matrix.

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45

Table 4 shows the manager-engineer's judgments regarding the problem's criteria and sub-criteria. The last column of the table shows the weighted priority of each element, as calculated with the process described in [18].

Note that a square matrix (of order n) is considered consistent if for n = 3, the C.R. is less than 5%; for n = 4, the C.R. is computed to be less than 9%; and for n > 5 if the C.R. < 10%. In the present case, all the matrices were consistent, and the judgments were as well.

Table 4. Pairwise comparison matrices, judgments, and priorities for risks and risk categories.

Risk ID	Pairwise Comparison Matrix												Local Priority (Score)	Global Priority (Score)
	R1	R2	R3	R4	R5	R6	R7	R8	R9	λmax	C.I.	C.R.		
R1	1	1	3	6	5	5	9	0.5	7	10.0284	0.1285	0.0887		0.2130
R2		1	4	5	5	5	7	0.333	7					0.2131
R3			1	5	3	3	5	0.50	5					0.1178
R4				1	0.333	0.333	5	0.333	3					0.0434
R5					1	1	5	0.333	3					0.0627
R6						1	6	0.25	3					0.0624
R7							1	0.143	0.2					0.0166
R8								1	7					0.2424
R9									1					0.0286
R1	<u>**0.2130**</u>	R1.1	R1.2	R1.3	R1.4	R1.5	R1.6	R1.7	R1.8	λmax	C.I.	C.R.		
	R1.1	1	3	5	6	5	6	5	7	8.8287	0.12184	0.0840	0.3648	0.0777
	R1.2		1	3	5	4	5	4	6				0.2209	0.0471
	R1.3			1	5	4	6	5	5				0.1701	0.0362
	R1.4				1	0.333	1	0.333	3				0.0377	0.0080
	R1.5					1	3	1	4				0.0718	0.0153
	R1.6						1	0.25	3				0.0363	0.0077
	R1.7							1	4				0.0749	0.0160
	R1.8								1				0.0235	0.0050
R2	<u>**0.2131**</u>	R2.1	R2.2	R2.3						λmax	C.I.	C.R.		
	R2.1	1	2	5						3.0536	0.0268	0.0462	0.5591	0.1191
	R2.2		1	5									0.3522	0.0751
	R2.3			1									0.0887	0.0189
R3	<u>**0.1178**</u>	R3.1	R3.2	R3.3	R3.4	R3.5				λmax	C.I.	C.R.		
	R3.1	1	1	3	5	5				5.3694	0.0923	0.0824	0.3719	0.0438
	R3.2		1	3	4	4							0.3339	0.0393
	R3.3			1	2	0.333							0.0903	0.0106
	R3.4				1	0.25							0.0550	0.0065
	R3.5					1							0.1491	0.0176
R4	<u>**0.0434**</u>	R4.1	R4.2	R4.3	R4.4	R4.5	R4.6			λmax	C.I.	C.R.		
	R4.1	1	2	1	5	3	0.50			6.1695	0.0339	0.0273	0.2167	0.0094
	R4.2		1	0.5	3	1	0.50						0.1153	0.0050
	R4.3			1	5	4	2						0.2908	0.0126
	R4.4				1	0.50	0.20						0.0448	0.0019
	R4.5					1	0.333						0.0836	0.0036
	R4.6						1						0.2489	0.0108

Table 4. *Cont.*

Risk ID	Pairwise Comparison Matrix												Local Priority (Score)	Global Priority (Score)
R5	**0.0627**	R5.1	R5.2	R5.3	R5.4	R5.5	R5.6	R5.7		λmax	C.I.	C.R.		
	R5.1	1	4	2	5	3	5	6		7.4733	0.0789	0.0598	0.3416	0.0214
	R5.2		1	0.333	2	0.5	3	3					0.1041	0.0065
	R5.3			1	3	2	4	5					0.2236	0.0140
	R5.4				1	0.20	0.50	3					0.0557	0.0035
	R5.5					1	3	5					0.1689	0.0106
	R5.6						1	5					0.0747	0.0047
	R5.7							1					0.0315	0.0020
R6	**0.0624**	R6.1	R6.2	R6.3	R6.4	R6.5	R6.6			λmax	C.I.	C.R.		
	R6.1	1	3	5	1	3	5			6.2913	0.0583	0.0470	0.3140	0.0196
	R6.2		1	2	0.5	1	3						0.1243	0.0078
	R6.3			1	0.2	0.2	3						0.0632	0.0039
	R6.4				1	3	6						0.3005	0.0188
	R6.5					1	5						0.1589	0.0099
	R6.6						1						0.0391	0.0024
R7	0.0167												-	-
R8	**0.2424**	R8.1	R8.2	R8.3	R8.4	R8.5	R8.6	R8.7	R8.8	R8.9	C.I.	C.R.		
	R8.1	1	4	7	6	6	3	3	7	7	0.1291	0.0890	0.3129	0.0758
	R8.2		1	6	3	4	0.333	0.250	5	7	λmax = 10.0324		0.1100	0.0267
	R8.3			1	0.200	0.250	0.167	0.167	0.333	3			0.0236	0.0057
	R8.4				1	1	0.200	0.200	3	5			0.0576	0.0140
	R8.5					1	0.200	0.200	2	5			0.0509	0.0124
	R8.6						1	0.333	6	7			0.1675	0.0406
	R8.7							1	6	7			0.2270	0.0550
	R8.8								1	4			0.0345	0.0084
	R8.9									1			0.0161	0.0039
R9	**0.0286**	R9.1	R9.2	R9.3						λmax	C.I.	C.R.		
	R9.1	1	4	6						3.0536	0.0268	0.0462	0.6910	0.0198
	R9.2		1	3									0.2176	0.0062
	R9.3			1									0.0914	0.0026

4.2. Priorities Calculation and Risks Ranking

The risks are weighted according to the higher level for the final ranking of the risks in order of importance. Accounting-wise, the result is obtained by multiplying the weight of each sub-criterion (local priority) with the weight of the criterion of the corresponding category to which it belongs, as previously calculated.

Table 5 presents the final results and rankings from the risk assessment analysis. The table is divided into four columns. The first column lists the overall ranking from the highest to the lowest risk factor. The second column details the risk ID, which identifies each specific risk factor. The third column shows the global priority percentage, which represents the weightage assigned to each risk factor based on the decision maker's expertise, experience, and judgments.

Table 5. Final results and ranking of the risk factors.

Ranking	Risk ID	Global Priority (%)	Ranking	Risk ID	Global Priority (%)	Ranking	Risk ID	Global Priority (%)	Ranking	Risk ID	Global Priority (%)
1	R.2.1	11.91%	13	R.9.1	1.98%	25	R.4.6	1.08%	37	R.8.3	0.57%
2	R.1.1	7.77%	14	R.6.1	1.96%	26	R.3.3	1.06%	38	R.1.8	0.50%
3	R.8.1	7.58%	15	R.2.3	1.89%	27	R.5.5	1.06%	39	R.4.2	0.50%
4	R.2.2	7.51%	16	R.6.4	1.88%	28	R.6.5	0.99%	40	R.5.6	0.47%
5	R.8.7	5.50%	17	R.3.5	1.76%	29	R.4.1	0.94%	41	R.6.3	0.39%
6	R.1.2	4.71%	18	R.7	1.67%	30	R.8.8	0.84%	42	R.8.9	0.39%
7	R.3.1	4.38%	19	R.1.7	1.60%	31	R.1.4	0.80%	43	R.4.5	0.36%
8	R.8.6	4.06%	20	R.1.5	1.53%	32	R.6.2	0.78%	44	R.5.4	0.35%
9	R.3.2	3.93%	21	R.1.3	1.40%	33	R.1.6	0.77%	45	R.9.3	0.26%
10	R.1.3	3.62%	22	R.8.4	1.40%	34	R.3.4	0.65%	46	R.6.6	0.24%
11	R.8.2	2.67	23	R.4.3	1.26%	35	R.5.2	0.65%	47	R.5.7	0.20%
12	R.5.1	2.14%	24	R.8.5	1.24%	36	R.9.2	0.62%	48	R.4.4	0.19%
										Sum=	100.00%

The final line of the table present" the summation of all the global priorities assigned to the respective risk factors, which must equal 100%, ensuring that all risks have been accounted for. It is essential to note that the most significant risk factor identified in this study was R.2.1, with a global priority percentage of 11.91%.

The risk management team of any construction project will find these findings to be of utmost relevance since they will enable them to recognize and rank the risks according to their level of significance. As a result, they can put effective preventive or mitigating measures in place to address these hazards, assuring the security of the construction site's workers.

These results further highlight the significance of utilizing a systematic risk assessment methodology, such as the Analytic Hierarchy Process, in identifying and assessing the risks associated with construction projects. It provides a comprehensive and transparent approach to analyze the relative importance assigned to each risk factor and prioritize the mitigation measures.

Overall, the results from the risk assessment analysis indicate that the project risk management team should focus on the risk factors with higher global priorities to manage the risks effectively. It is important to note that risk assessment is an ongoing process and should be continually monitored to account for new risks identified during the course of the project.

5. Conclusions

During the construction of a technical road construction project, many potential risk factors in the construction site environment threaten the safety and health of workers.

Many of the same risks are presented simultaneously in more than one construction stage, while in each phase of the project, two or more different categories of risks are identified.

It was found that the risks come from the use of machinery, falls from a height, exposure to harmful agents (physical, chemical, and biological), ground failures, working conditions, and other causes present in the construction environment of the project. An approach was also taken to the psychosocial risks identified in a work environment regarding their effects on the worker at the road construction site.

The risks identified were grouped into nine categories, comprising a total of forty-eight risks, divided into each category according to their triggering factors.

The evaluation of the above risks in terms of their effects on the health and safety of workers and to qualify for the most critical risks was carried out in a specific road construction project (case study). The problem was tackled with the process of multicriteria analysis and specifically with the AHP method. After structuring the hierarchy of the problem, rendering judgments concerning the weight of importance of the risks according to the nature and specificities of the specific project and the necessary control of the consistency of the judgments, the final ranking table and the overall priorities of the risks emerged.

The ranking order shows that the most important risk is a worker's fall from working floors at a height (bridge or tunnel). The most critical risks are found in machinery and project vehicles, worker falls from a height, ground failures or collapses, and exposure to harmful factors. The result follows reality as, according to the statistics and literature sources, the risks mentioned above, and risk categories are associated with the highest rates of accidents and impacts on the health and safety of road construction workers.

Regarding the risks that are presented in the ranking table as of minor importance (percentage of less than 1%), this happens for reasons such as:

Due to the nature of the project, no (or minimal) tasks may cause such risks. Thus, the gunite machine operator injury, or the risk of cement detachment from a height and the risk of flying materials, are caused mainly by the tunnel dome's construction work. The tunnel was finished in the current project, and the dome was built in a previous contract.

The decision maker's knowledge and experience may not include such risks. Risks, such as sanitary facilities or microclimate, are not widely known, or there is no evidence since their effects are not immediate and are encountered later.

The cumulative percentage of low risks on the ranking table is high, so the risks should be addressed. It is concluded that the application of AHP to the evaluation of the problem produced reliable results. However, other less-known ones that escape the decision-maker's experience are set aside or ignored. Updating the risk impact statistics and applying group decision-making methods would further strengthen the reliability of the results concerning reality. Nevertheless, the contribution of the method to the evaluation of the specific problem is considered particularly important. The final prioritization of the risks and the highlighting of the most important ones for the safety and health of the workers enables the contributors of the project to make appropriate decisions for its management in terms of the specific risks that have been qualified (e.g., redistribution of financial resources of the project for risks related to the project's security measures).

The Analytical Hierarchy Process (AHP) is not without limitations when applied to risk assessments. A key disadvantage of AHP is its dependence on expert judgments and subjective criteria, which are crucial to the accuracy and reliability of the results obtained. This means that decision makers' knowledge and expertise perform a significant role in identifying and prioritizing risks. Consequently, limited knowledge or experience may result in inaccurate or incomplete risk identification and ranking. Additionally, applying the AHP model to a large number of criteria or alternatives may be challenging, which could hinder obtaining an accurate ranking of risks.

AHP has a further limitation in that it may not account for all the interdependent factors that are associated with risks simultaneously. This can culminate in situations where different risk factors are connected, and the risk mitigation measure adopted for one vulnerable aspect may trigger fresh risks. Consequently, AHP may fail to fully include these interdependencies and their potential influence on the risk assessment outcomes.

Additionally, AHP only considers the relative importance of the risks and their priorities, ignoring the stochastic nature of the risks. This might not serve as a sufficient foundation for the creation of probabilistic models or for calculating the likelihood that a negative event will occur.

In conclusion, while the Analytical Hierarchy Process is a useful method for risk assessments, there are some drawbacks that must be taken into account. As a result, it should be used in conjunction with other risk assessment techniques, and its limitations should always be considered when interpreting the results.

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