Vol. 15, No. 43, Summer 2025, pages 11-20

Journal of Analytical and Numerical Methods in Mining Engineering

Journal home page: http://anm.yazd.ac.ir/

Research article

# Risk analysis and reducing measures in tunneling project of Tabriz metro line 2

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(Received: *June 2024*, Accepted: *December 2024)*

*DOI: 10.22034/ANM.2024.21743.1640*

***Keywords***

**Mechanized excavation**

**Risk analysis**

**Probability**

**Risk management program**

**Geotechnical risks**

***Abstract***

Risk management and control are essential tools in various engineering fields, particularly in tunneling projects, which are inherently associated with a high degree of uncertainty and risk. Due to these uncertainties, risk management plays a crucial role in such projects. Given the complexity of tunneling, especially in urban environments, it is vital to identify, evaluate, and analyze risks throughout the project lifecycle. This study examines the geotechnical conditions of Tabriz Metro Line 2, taking into account factors such as the tunnel boring machine (TBM), support structures, and human resources. The risks along the project route have been identified, prioritized, and mitigation strategies have been proposed to reduce these risks. The risks in the Tabriz Metro Line 2 project were categorized into six main groups: geotechnical hazards, excavation machinery, construction period, support and human resources, design and research phase, and management. Each category's hazards were identified, evaluated, and key influencing factors were analyzed. Based on the risk analysis results, the risks were classified into high, medium, and low categories, and appropriate mitigation measures were suggested for each level of risk. Through the implementation of effective risk response techniques, high-risk hazards were reduced by 39%, and medium-risk hazards were reduced by 23%. This research provides valuable insights that can improve the overall quality and efficiency of the Tabriz Metro Line 2 tunneling project.

## 1. INTRODUCTION

In recent years, the excavation of underground spaces, particularly urban transport tunnels, has gained significant importance due to population growth and increasing traffic issues. In past decades, various methods, ranging from traditional to semi-mechanized, have been used for tunnel excavation. However, with advancements in technology, fully mechanized methods, such as tunnel boring machines (TBM), have been developed. Traditional methods of urban tunnel excavation face several challenges, including ground control and support, preventing surface settlement, controlling groundwater inflow, and, most importantly, ensuring the safety and health of personnel. These challenges often result in increased costs and longer project durations. Mechanized excavation has thus emerged as the preferred alternative, enabling the excavation of long tunnels in diverse geotechnical conditions with fewer workers and shorter timeframes. While mechanized methods involve fewer risks compared to traditional approaches, they still carry risks at every stage, mainly due to their relatively new nature and the lack of sufficient knowledge regarding their use. Numerous studies have been conducted on risk assessment and management in tunneling projects. For example, Ehrbar and Kellenberger (2003) implemented a risk management program in the Gotthard tunnel, identifying geology as a central risk factor [1]. Moergeli (2004) explored risk management in tunneling occupational health and safety programs, proposing methods for controlling key success factors through effective operational risk management [2]. Schmitt (2006) assessed the risks involved in using a TBM in crushed rock for Greece’s Kallidromo tunnel, demonstrating how construction methods influence risk types [3]. In addition, Geun (2008) calculated geotechnical stability risks using safety factor classification, focusing on potential damage due to ground settlement near tunnels [4]. Emadi et al. (2010) investigated geotechnical risks in EPB excavation for Tehran metro line 7, offering strategies to ensure safe conditions [5]. Sayadi et al. (2011) created a comprehensive risk structure for the Simreh Dam tunneling project in Iran, categorizing risks into 17 main groups and 196 sub-levels [6]. Further research includes Lieb and Ehrbar's (2011) comprehensive application of risk management in the Gotthard tunnel project, addressing both threats and opportunities at operational and strategic levels [7]. Song and Wang (2011) studied ground risk mechanisms in the Shenzhen tunnel in China, identifying and evaluating major risks using a risk calculation model [8]. Likhitruangsilp and Ioannou (2012) analyzed risk response measures for the tunneling project in Thailand, identifying 39 risk factors and reviewing them with experts [9]. Chang et al. (2019) used a Bayesian network to investigate excavation risks for shield TBMs, estimating risk levels based on geological hazards, TBM types, and errors during excavation [10]. Wagh et al. (2021) assessed underground excavation risks for the Pune metro using a risk matrix and expected monetary value (EMV) analysis [11]. Li et al. (2022) applied the AHP-FSE method to evaluate risks and recommend risk-reduction measures in grout shield construction, focusing on managerial, economic, and technological aspects [12]. Koohathongsumrit and Meethom (2024) introduced a data analysis model for assessing TBM excavation risks in Thailand’s metro project, using the best-worst method to classify critical and less severe risks [13]. The primary goal of this study is to identify and evaluate the risks associated with the Tabriz Metro Line 2 and propose strategies to minimize them. The risk management process is based on the PMBOK (Project Management Body of Knowledge) standard, widely recognized as the global standard in project management. PMBOK provides a universal framework for evaluating project management systems, with common definitions and classifications derived from this standard [14]. In this research, risks have been identified, evaluated, and analyzed according to the project's geotechnical conditions, excavation machinery, support systems, human resources, design phase, and management. The risks have been prioritized, and appropriate mitigation measures have been recommended. This study aims to improve the quality and efficiency of the Tabriz Metro Line 2 tunneling project.

## 2. RISK MANAGEMENT

The risk management process involves identifying potential hazards in tunneling activities, estimating their likelihood of occurrence, and assigning a risk importance index. Mitigation measures are then applied to reduce both the likelihood and severity of these hazards. Risk levels are determined by multiplying the probability of occurrence by the impact severity index, producing the initial risk level. If the initial risk is unacceptable, further mitigation strategies are identified and implemented. The remaining risks, known as residual risks, are re-evaluated to ensure they are within acceptable levels. Urban mechanized tunneling is inherently risky due to uncertainties related to geology, hydrology, and construction conditions. These risks can negatively impact safety, time, costs, and environmental aspects of a project. A Risk Management Program (RMP) is a comprehensive approach that includes clearly defined procedures and tools. The main goal of an RMP is to ensure that risks are reduced to acceptable levels. An effective RMP is based on four key principles:

1. Detecting and identifying risks

2. Defining project goals and requirements

3. Establishing risk tolerance levels for stakeholders

4. Determining a reference scenario and documenting identified risks

Risk analysis includes both qualitative and quantitative methods. Qualitative analysis is commonly used in the initial stages, while quantitative analysis is employed when data is insufficient for statistical analysis. Scoring risk probability is based on the likelihood of an event. A score of 5 represents events that are likely to occur frequently, while a score of 1 represents events with a negligible probability. Severity is scored based on the event’s potential damage to the project, such as delays, additional costs, reduced quality, or injuries to personnel.

## 3. INTRODUCING TABRIZ METRO LINE 2

Tabriz Metro Line 2 begins in the Qaramalek area in the western part of Tabriz and runs through several key locations, including Qara Aghaj, Joumhouri, Daneshsara Square, and Abbasi Street, before reaching Shahid Fahmideh Square. The line then extends eastward, terminating near the Tabriz International Exhibition Center (Fig. 1). The total length of this metro line is approximately 22.5 km. The tunnel has an outer diameter of 9.49 m, an inner diameter of 8.48 m, with a segment thickness of 35 cm and an injection area thickness of 15.5 cm. Along the route, the tunnel depth ranges from 15 m to 28 m. Excavation is being carried out using a fully mechanized method with the installation of precast segments. To identify the geological and engineering hazards along the route, comprehensive studies have been conducted. These studies include data from several boreholes, along with field and laboratory test results. The selection of the tunnel boring machine (TBM) for Tabriz Metro Line 2 was based on the physical characteristics of the soil layers encountered along the route. One of the most important geological features of Tabriz is its soft soils and alluvial sediments. Additionally, the groundwater level throughout the route is higher than the tunnel depth. Given the presence of clay and silt layers along the tunnel route, an Earth Pressure Balance (EPB) machine is the most suitable choice for excavation. Moreover, due to the high moisture content in these layers, the excavation process requires the use of additives and polymeric foams to manage the soil conditions effectively.

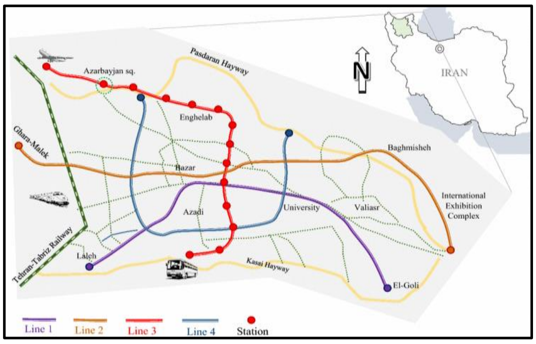


**Fig. 1. General layout of the Tabriz metro network.**

## 4. TUNNELING HAZARDS OF TABRIZ METRO LINE 2

The tunneling project for Tabriz Metro Line 2 involves several categories of risk, including geotechnical hazards, excavation machine hazards, construction period hazards, research and design phase hazards, and management hazards. Fig. 2 presents the distribution of each identified hazard, which was determined using the simple counting method [15]. These hazards were identified by considering the specific characteristics of the project as well as insights gained from previous similar projects. According to the definition of risk sources—any factor or activity that has the potential to cause damage—the following hazards have been identified as initial risk sources in urban mechanized tunneling, along with their respective origins:

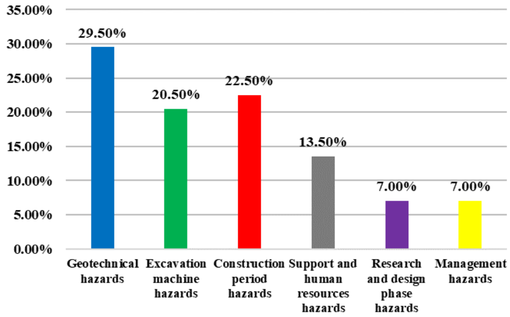


**Fig. 2. The percentage of each category of identified hazards [15].**

### 4.1. Geotechnical Hazards

In general, the sources of creating geotechnical risks in a mechanized excavation project are:

- Ground surface settlement and creation of a hole (R01)
- Tunnel face instability (R02)
- The behavior of soil cohesion and clogging (R03)
- The absence of fine grains (the percentage passing through the sieve 200) (R04)
- High permeability of the soil (R05)
- The potential of dangerous gases entering the tunnel (R06)
- Water rushes into the tunnel (R07)
- Abrasive soils and large pieces (R08)
- Collapse and unexpected geotechnical stress conditions (R09).
- Soil swelling (R10)
- A gap or sudden changes of materials on the tunnel face (R11)
- Chemical corrosion (R12)
- Lack of information in a part of the route (R13).

### 4.2. Hazards Of The Excavation Machine

The sources of hazards of the excavation machine are:

- Shield jamming of the excavation machine (R14)
- Deviation of the excavation machine from the main path of the tunnel (R15)
- Low advance rate of excavation machine (R16)

- The curvature of the shield of the excavation machine (R17)
- Premature destruction of excavated cutting (R18)
- Blocking of the excavation machine due to the instability of the tunnel face (R19)
- Cutterhead jamming of the excavation machine (R20)
- Wear and tear of the bit and cutterhead (R21)
- Breakdown of the excavation machine (R22)

### 4.3. Hazards Of The Construction Period

In the tunnel construction process, there are hazards related to the construction period. The sources of these risks include:

- Damage to structures and buildings in the tunnel route (R23)
- Segment surface cracking and fracture (R24)
- Spacing of segment and ring (R25)
- Incorrect geometry of the installed segment (R26)
- Floating lining ring (R27)
- Water entering from the surface and the junction of the segments (R28)
- Falling of the segment from the joint (R29)
- Escape of pollutants into the environment (R30)
- Urban traffic (R31)
- Explosion and fire incident (R32).

### 4.4. Hazards Of The Support And Human Resources

The probability of occurrence and the impact intensity of support and human resources hazards have been determined according to the checklist prepared by managers and experts in the field of tunneling project management. The sources of hazards related to support and human resources are as follows:

- Support and logistics hazards (R33)
- Hazards of contractual issues (R34)
- Maintenance hazards (R35)
- Hazards of municipal permits to start operations (R36)
- Acquisition of the entrance and exit shaft of the tunnel (R37)
- Sanctions (R38).

### 4.5. Hazards Of Research And Design Phase

The sources of hazards of the research and design phase include:

- The hazards of choosing an excavation method (R39).
- The hazards of the type of support system and the method of construction and implementation (R40).
- The hazards of identifying the location of the historical building (R41).

### 4.6. Management Hazards

From the point of view of project management, risks should be identified and controlled as much as possible to minimize the damage caused by them. In general, every organization or project will encounter three types of hazards: political hazards, force majeure hazards, and contractual hazards. Managers, especially project managers, have few tools to control political hazards and force majeure. However, in the case of the third type of hazards, they should exercise full control so that the time and costs of the project are fully under control. The sources of management hazards are the following:

- Project execution time (R42)
- Project cost (R43)
- Project implementation quality (R44).

## 5. RISK ASSESSMENT OF IDENTIFIED HAZARDS

To evaluate the damage pattern, the damage intensity and the probability of its occurrence should be estimated. The damage intensity can be estimated using cost and time evaluations, while estimating the probability of occurrence is much more difficult.

Therefore, the probability of occurrence is evaluated based on experience. This condition is certainly for when the parameters and characteristics of the ground are determined. The experience of estimating the probability of occurrence can be collected and used from other projects that have similar conditions to the characteristics of the project site.

Detailed exploration of ground characteristics by running an exploratory tunnel or experimental gallery and by performing instrumentation and back analysis can lead to improved estimation of the probability of occurrence of the damage pattern. Risk analysis should be done completely based on expert opinion.

In order to achieve to probability of occurrence, the method of preparing a checklist has been used to obtain the probability of the event. The checklists are designed to list the main and important causes of each hazard. Also, the probability of occurrence and the impact intensity of these causes have been determined based on the project's characteristics and experiences gained from previous projects. The checklists have been completed by three different groups of experts in the field of tunnel management, design, and excavation. Using statistical techniques, the probability and impact intensity of each hazard have been calculated. The management group includes people such as managers of the Tabriz metro and project managers of Tabriz metro lines 1 and 2 in the design and contracting teams. The design group includes consulting engineers involved in the project of Tabriz line 2. Also, the excavation group includes engineers involved in the Tabriz lines 1 and 2.

### 5.1. Creating Initial Risk Matrix

Using the Risk Management Program (RMP), an initial risk matrix is prepared to identify critical risks and guide the subsequent steps in the risk management process. This matrix is composed of 5 rows and 5 columns, where each cell represents a different risk level. The matrix assigns values by multiplying the probability of occurrence by the severity of impact. The highest possible value in this matrix is 25, which corresponds to hazards with the greatest risk. Fig. 3 and Fig. 4 show the initial risk matrix.

| | | Probability of occurrence | | | | |
|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 |
| Impact intensity | 5 | R01 R23 R42 | R14 R32 R34 R26 | R09 R13 R15 R29 R39 R02 | R06 R27 R39 | |
| | 4 | R16 R18 R38 | R08 R17 R20 R21 R24 R25 R36 R43 R44 | R03 R05 R07 R11 R33 R35 R26 R40 | R04 R19 R30 R41 | R10 |
| | 3 | | R28 | R31 | R37 | |
| | 2 | | | | R12 | |
| | 1 | | | | | |

**Fig. 3. The matrix of analysis of technical and operational risks.**

| | | Probability of occurrence | | | | |
|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 |
| Impact intensity | 5 | R42 | R32 R34 R43 | R02 R35 | | |
| | 4 | R38 | R14 R20 | R1 R29 R33 R40 R39 | R19 R37 R41 | |
| | 3 | R16 R01 R18 R23 | R0 R17 R24 R26 R36 R44 | R03 R05 R13 R11 R09 R07 R22 | R27 R12 R04 | R10 |
| | 2 | | R25 R21 | | R06 R30 | |
| | 1 | | R31 | R28 | | |

**Fig. 4. The matrix of analysis of Economic risks.**

### 5.2. Analysis Of Initial Risks

Fig. 5 demonstrates the percentage of high-risk occurrences across different risk categories from these two points of view.

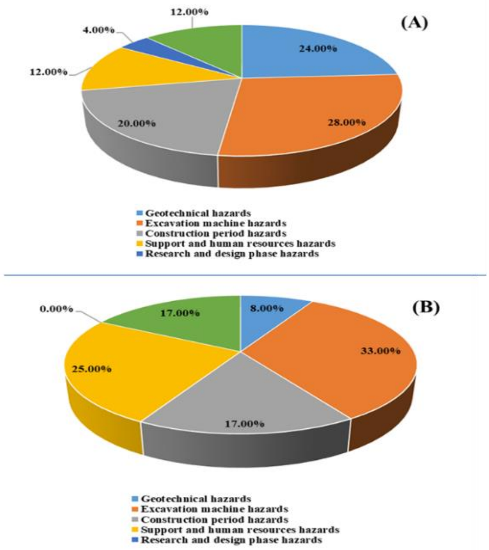


**Fig. 5. Percentage of high risks for each category of risks a). Technical-operational point of view b). Economic point of view.**

## 6. PREPARATIONS AND ACTIONS AGAINST IDENTIFIED RISKS

During the design and construction of urban tunnels, despite time and cost limitations, it should be ensured that the project is carried out with minimal damage and injuries, following the specifications and requirements of the employer. For most construction projects and urban mechanized excavations, there are principles and rules that the project manager must follow. In urban mechanized excavation, in addition to implementing the project in accordance with the standards and requirements of the employer, a set of separate components or influencing factors on management, design, and construction, selection of excavating machine, and other parts related to the project should be considered. Because mechanized excavation is carried out in an urban environment, the minimum amount of disturbance on the ground surface, the minimum amount of damage to structures and buildings affected by the project, and the minimum amount of damage to underground facilities and structures, etc. should be caused so that the project goals, including cost, time, and quality, do not fail. For this purpose, the risks identified in the initial stages of risk management should be analyzed to estimate the importance of each risk. An important step to achieving the project goals is to respond to the identified risks. Undoubtedly, the first response to risk is choosing the right construction method. By using mechanized excavation with shield TBMs, it is possible to construct tunnels in urban environments with minimal disruption to urban activities. In the following, mitigating measures for the analyzed risks will be reviewed.

According to the score matrix of the initial risks formed in the previous section, the risk response process should be applied accurately to the initial risks. Some risks should be transferred to the employer, contractors, insurance organizations, and even the customer themselves. There are risks for which the risk avoidance technique is used. The risk can be avoided by allocating additional cost and time. The risk mitigation measures are actions taken before and during a project to reduce the probability and impact intensity. Fig. 6 shows the principles of risk management.

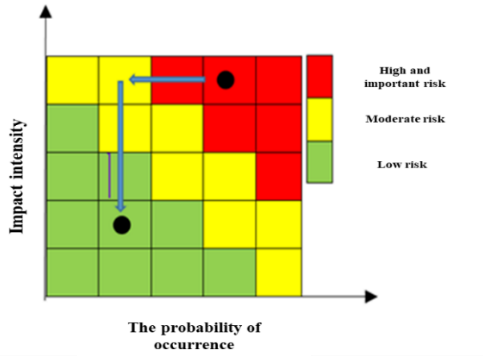


**Fig. 6. Principles of risk management.**

In general, possible measures to reduce risk can be categorized as follows:

### 6.1. Mitigation Measures For Geotechnical Risks Of The Tunnel Route

Mitigation measures for geotechnical risks include:

- Proper instrumentation and monitoring system on the ground surface
- Soil Conditioning
- Accurate control of face pressure
- Continuous control of injection parameters, including injection volume and pressure
- Using a special slurry mixing plan
- Monitoring and control of the stability of the tunnel face.
- Regular calibration of gauges
- Adequate and appropriate geotechnical studies
- Conducting additional studies to identify critical areas
- Bentonite injection behind the excavation shield
- Proper drainage system
- Use of polymer foam injection to the tunnel face
- Instrumentation and accurate monitoring of fault zones
- Implementation of appropriate pillars
- Permanent filling of old holes and aqueducts
- Deviation of existing underground facilities
- Using PVC pipes in the walls of exploratory boreholes
- Using cement with anti-corrosive properties against water
- Use of concrete with the right grade based on the corrosiveness of water and the lifespan of the tunnel.

### 6.2. Mitigation Measures For The Excavation Machine Risks

To reduce the hazards of the excavation machine in the project of Tabriz metro line 2, a series of preventive and corrective measures can be implemented as follows:

- Choosing the right and sufficient trust for the excavation machine
- Choosing a device equipped with a bentonite injection system behind the shield
- Selecting a device equipped with a geophysics system while moving forward of the excavation machine
- Choosing a device with a suitable grid in front of the cutterhead
- Ability to adjust the opening ratio of the excavation machine
- Mapping system mounted on the excavation machine
- The activation of all lines and injection lancers
- Installation of$H_2S$ gas and methane gas detection sensors
- Segment Erector equipped with a remote control system
- Equipping an excavation machine with a crusher mounted on it in the front part of the cutterhead
- Equipping the machine with a weighing system on the conveyor belt
- Having a precise sealing system
- Using a cutting tool suitable for the route soil.

### 6.3. Mitigation Measures During The Construction Period

The most important stage in which the risks related to the project are more visible is the construction stage. During this phase, the following steps should be taken:

- Instrumentation of adjacent buildings
- Using a shield or implementing a concrete barrier between the building and the tunnel
- Using retaining pins for building foundations
- Maintenance program for nearby buildings

- Performing hyperbaric before or after the critical zone
- Surveying of existing buildings and structures
- conducting vulnerability studies of buildings and structures
- Risk analysis of the building and adjacent and affected structures
- Designing a suitable depot system for the segments
- Observing safety tips for segment transportation
- Implementation of the segment construction quality control program
- Implementation of the segment installation control program
- Repairing the segment at the depot and issuing a confirmation sheet
- Using experienced operators and personnel training
- Visiting the installed parts to prevent the creation and expansion of cracks
- Applying symmetrical and appropriate injection pressure
- Using quick-setting materials to remove the late-setting of the grout
- Secondary injection
- Repairing the entrance of water into the tunnel
- Careful maintenance and repair
- Segment transportation at night or on holidays.

### 6.4. Mitigation Measures In The Support And Human Resources Phase

- Support planning, procurement, and proper monitoring and management
- Formation of the project team and its development and management
- Obtaining the approval of the technical specifications of the items entering the workplace
- Participation in planning and monitoring
- Use of design and implementation contracts
- Clarification of contractual provisions
- Using contractors with high management ability
- Checking the initial conditions and the environmental and working conditions of the devices
- Method and quality of implementation of construction operations
- Complete investigation of the opinions of the manufacturer of the devices
- Timely availability of materials and spare parts
- Analysis of the main causes of failure
- Periodic repairs at regular intervals
- Fixing possible faults and defects, and preventing the occurrence of major damages
- Regular inspection of equipment
- Cooperation with the relevant executive company
- Frequent follow-ups
- Employing experienced and committed contractors and executive teams
- Personnel training
- Allocation of funds for property release
- Use of engineers and internal force
- Use of global market intermediaries.

### 6.5. Mitigation Measures In The Research And Design Phase

- Guidelines for the assessment of the advance rate and the pressure of the designed tunnel face, and applied in the construction phase
- Using valid theoretical methods to calculate important design parameters
- Providing proper instructions for quality control
- Equipping the laboratory at work
- Compilation of the quality assurance system and its follow-up
- Considering a higher safety factor in the design
- Partnership with cultural heritage organizations and organizations related to historical buildings to obtain information about the location of buildings
- Simulating and analyzing the amount of ground surface settlement.

### 6.6. Mitigation Measures To Improve The Project Management Phase

- Providing adequate liquidity
- Correctly defining the key points and critical paths of the project and creating timely alarms
- Timely supply
- Proposing financing solutions to the employer (using finance conditions and government bonds, and the city budget)
- Use of properties owned by the municipality for clearing
- Using appropriate contracts such as EPCF or other models
- Definition of the system and specific chart of the quality control system.

### 6.7. Measures To Transfer Risks

According to the experiences in the project of Tabriz metro line 2, there are hazards that the related risk should be transferred. In the case of risk transfer, secondary risks will occur in the project, and these risks must be identified and evaluated.

- Contractors: For risk transfer, contractors are a suitable option. The excavation contractor is used to transfer part of the risk of the construction hazards and the hazards of the excavation machine, such as machine stoppage, low machine advance rate, and project budget (for example, the initial investment to buy the machine).

- Segment manufacturing factory: by transferring the responsibility of high-quality segments to a segment factory with separate management, under the supervision of consulting engineers and developing a system for confirming segments in accordance with design and manufacturing standards, hazards such as the wrong geometry of the manufactured segment, failure of the manufactured segment to reach the ultimate strength, segments with cracks and fractures in the manufacturing process, etc. are transferred.

- Insurance organization: Regarding the hazard of explosion and fire, despite the mitigating measures to reduce the probability of the event, the risk of this hazard should be transferred to the insurance organization. All engineers, supervisors and workers, and the excavation team can be covered by accident insurance.

- Employer: shareholders and employers can participate in any field of hazards. They can play a significant role in managing the remaining risks by timely provision, sharing the profit from the project, etc.

- Customer: Despite the application of mitigation measures on different parts of the project, hazards such as the cost of the project, the time of the project, and even the quality of the project have medium and high risks. Therefore, a part of these remaining risks should be transferred to the customer (for example, estimating the customer's consumption price).

### 6.8. Assessment Of Remaining Risks

Using the risk management plan built into the risk management process, a score matrix can be formed for the remaining risks. Risk response measures can move risk from a high-risk area to a low-risk area. Hazards that are still high risk after risk response measures should be reported. Depending on their type, these hazards can be used in cost and time estimation for the employer, contract amount for contractors, and price estimation for the customer. In Figs. 7 and 8, the score matrix of the remaining risks is described using the RMP table.

| Impact intensity | Probability of occurrence: 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | R42 | | R43 | | R44 |
| 3 | | | R09 R14 R16 R18 R23 R24 R25 R36 R38 | R02 R06 R10 R21 | R07 R13 R15 R22 R26 R27 R30 R31 R33 R39 R40 |
| 2 | | R08 | R01 R11 R28 R32 | R03 R05 R19 R20 R37 | R04 R29 R41 |
| 1 | | | | R12 R17 R34 R35 | |

Fig. 7. Score matrix of remaining risks from a technical-operational point of view.

| Impact intensity | Probability of occurrence: 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| 5 | | | | | |
| 4 | | | R25 R38 | | R44 |
| 3 | R42 | | R11 R16 R24 R43 | R05 R21 R37 | R13 R22 R39 R41 |
| 2 | | | R01 R14 R09 R18 R23 R36 | R20 R34 R02 R12 R17 R35 | R04 R33 R07 R15 R30 |
| 1 | | R08 | R28 R32 | R06 R03 R10 R19 | R26 R27 R29 R31 R40 |

Fig. 8. Score matrix of the remaining risks from an economic point of view.

According to the risk score matrix formed by the risk management program, the initial and remaining risk scores for technical-operational risks and economic risks have been determined. Therefore, by using the distribution of initial risks and residual risks, the occurrence probability of events with high, medium, and low risk and the probability of residual risks with high risk have been determined.

Figs. 9 and 10 show the pie charts of risks before and after mitigating measures as a percentage of total hazards.

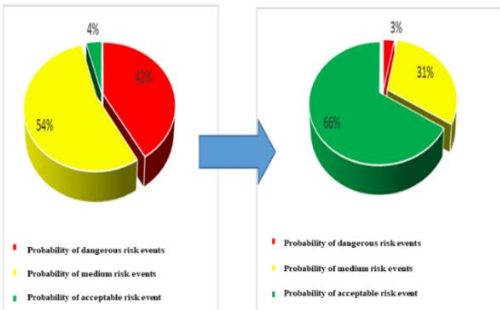


Fig. 9. The percentage of high, medium, and low risks from a technical-operational point of view.

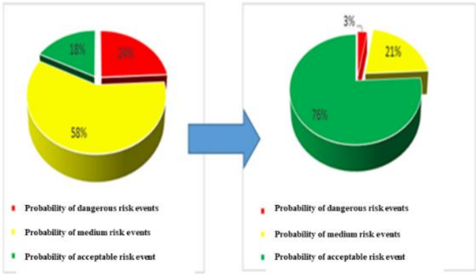


**Fig. 10. The percentage of high, medium, and low risks from an economic point of view.**

Hazards with high and important risks are unacceptable, and construction operations should not start before the risks are reduced. If the unacceptable risks in the project are not reduced, there is a risk of stopping the project. Based on the estimates made in this study, the unacceptable risks in the project of Tabriz metro line 2 are 42% from the technical-operational point of view and 24% from the economic point of view. By carrying out the risk response process, the high risks from the technical-operational point of view and from the economic point of view have reached the value of 3%.

In the case of important and low risks, construction operations can be started, but mitigation measures should be applied and solutions should be proposed to optimize costs. These risks are 54% from the technical-operational point of view and 58% from the economic point of view before the mitigation measures. Using risk response techniques, these risks have reached 31% and 21%, respectively. Fig. 11 shows the distribution of risks before and after mitigating measures from a technical-operational and economic point of view.

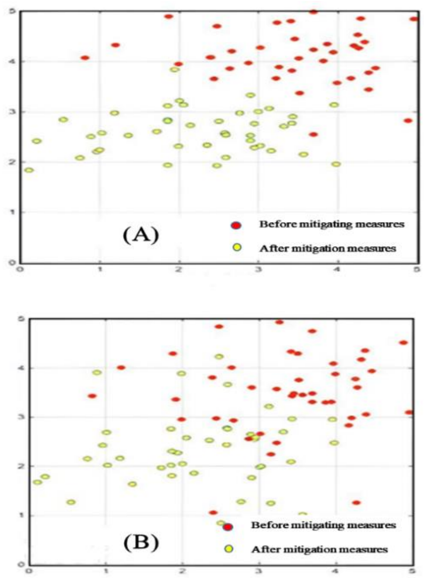


**Fig. 11. Risk distribution, before and after mitigating measures a). The technical-operational point of view b). The economic point of view.**

## 7. CONCLUSION

In high-risk tunneling projects in urban environments, such as Tabriz Metro Line 2, evaluating and ranking risks during the initial stages is critical for effective risk management and ensuring project success. This study identified and analyzed the risks associated with this specific tunneling project, providing insights into the distribution of hazards and the effectiveness of mitigation measures. The key findings are summarized as follows:

Risk Categories and Distribution:

The study identified six main categories of hazards: geotechnical hazards, excavation machine hazards, construction period hazards, support and human resources hazards, design and research phase hazards, and management hazards. The distribution of hazards was as follows:

Geotechnical hazards: 29.5%

Excavation machine hazards: 22.5%

Construction period hazards: 20.5%

Support and human resources hazards: 13.5%

Design and research hazards: 7%

Management hazards: 7%

High-Risk Hazards:

From a technical-operational perspective, 57% of the hazards were initially categorized as high risk and unacceptable. From an economic perspective, 27% of the hazards were high risk. Specifically, excavation machine hazards contributed to 28% of the high-risk technical-operational hazards and 33% of the high-risk economic hazards. Geotechnical hazards and construction period hazards were also significant contributors to high risks.

Highest Risk Hazards:

The most severe risks, accounting for 7% of the total hazards, were related to:

Ground surface settlement and the potential for creating voids

Damage to nearby structures and buildings

Management of project execution time

Critical Risk Factors:

Several factors were identified as major contributors to high and unacceptable risks, including:

Ground surface settlement and rock falls due to over-excavation

Inadequate control of face pressure and shield settlement

Issues related to abrasive boulders and improper support conditions of the excavation machine

Project delays, particularly due to a lack of control over machine stoppages and poor time management

Inaccuracies in EPC contracts and coordination issues with the employer

Risk Reduction Achieved:

Implementing risk response processes led to a significant reduction in risks:

Technical-operational risks: High-risk hazards decreased by 39%, and medium-risk hazards decreased by 23%.

Economic risks: High-risk hazards decreased by 21%, and medium-risk hazards decreased by 37%.

Remaining High-Risk Hazards:

Despite the mitigation efforts, 3% of the hazards still remain high risk. The most critical of these remaining risks is related to the management of project execution time, which continues to pose a significant threat to the project's timeline and overall success.

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