Risk Analysis and Risk Ranking in Tunneling: A Case Study

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ABSTRACT

Constructing tunnels underground is generally described as a high-risk activity because conditions in the surrounding area tend to be unpredictable. This would and can create unique dangers in every situation.

It is important to gain a deep understanding of the risks associated with tunneling in order to reduce the likelihood of their occurrence and severity of their consequences should they occur. For this to be achieved, different risks should first be evaluated and ranked according to their relative importance and criticality.

The Amir Kabir tunnel is considered one of the most dangerous tunnels in Tehran, Iran, in terms of the risks involved in its excavation and their potential consequences. In particular, part T4 of the tunnel passes through a zone of different strata and also a compound of various soils.

This paper studies part T4 of the Amir Kabir tunnel from a risk analysis and risk management point of view. In doing so, factors increasing total cost, causing delay in the project completion time, decreasing the operation rate and downgrading project quality were identified and ranked according to their importance using the aggregate primary index risk method. For this purpose, a comprehensive questionnaire was designed and completed by tunneling experts. By responding to the questionnaires, the experts determined the relative likelihood of occurrence of the studied factors and their potential consequences. As a result, the experts suggested several alternatives to reduce the risks involved in this particular study. Moreover, the experts completed new questionnaires whilst taking into account different alternatives. In the next step, the risks before and after applying the alternatives were compared. As a result of performing the said analyses, it was concluded first that the aggregate primary index risk is an effective tool in identifying the risks involved in such projects. Second, it was concluded that, by taking into account different alternatives when analyzing and ranking the risks, severity of the said risks can potentially be reduced. Also, by considering such matters when analyzing tunneling risks, the projects' efficiency can greatly increase as a result of reducing risks that threaten financial and human resources. The approach introduced in this paper, together with the methodology described, can be adopted by the mining design engineer in all similar situations. They will be of particular advantage in such methods as room and pillar mining, where the number of similar tunnels required is high.

INTRODUCTION

The speed at which tunneling projects are being carried out has increased dramatically in recent years in Iran.

Constructing tunnels underground is generally described as a high-risk activity because conditions in the surrounding area tend to be unpredictable. This would and can create unique dangers in every situation.

The word "risk" has varying meanings, depending on different contexts used. To the common man, risk simply is the concept of probability and severity of an outcome (Oraee-Mirzamani, 2014). Many studies on this have been carried out by scholars due to its importance in every project. For example, Sharifzadeh et al., in their research, chose the most convenient Tunnel Boring Method (TBM) to excavate the Nosoud tunnel using risk analysis (2008). Baccarini analyzed the effect of time, cost and quality on ranking project risks using risk management techniques (Baccarini, 2001). Furthermore, Beard analyzed tunneling safety management and the decrease in risk using different indices (2010), and Isaksson explained the cost, design time and building the underground tunneling projects in a function of probability (Isaksson and Stille, 2005).

Although many tunneling projects have been carried out in safe conditions, unexpected events have also happened in some projects, resulting in delays, an increase in project costs, injuries and death (Sousa, 2012). Therefore, risk analysis and risk management is a crucial part of any tunneling project. Risk evaluation is a part of risk management that can help decision makers to consider better reactions and perceptions by ranking the existing dangers (Fouladgar et al., 2012).

The aim of this paper is to rank the risks associated within the part T4 of the Amir Kabir tunnel project using the aggregate primary index risk in terms of their criticality and importance.

THE AMIR KABIR TUNNEL

The project of constructing the Amir Kabir tunnel is one the most important projects in Tehran; it commenced in 2009 and is located in the east of Tehran's Bazaar. The tunnel is 2350 m long and divided into six main parts.

The first part is an underpass, which has been constructed using the cut-and-cover technique. The second part holds a two-sided tunnel that passes under a street beneath a construction site with a three-story underground parking structure and four-story building with its basement connected to the tunnel. The fourth part consist of a two-sided tunnel that passes under a street which then divides into two one-sided tunnels at a major square. The fifth and sixth parts begin from the square as two one-sided tunnels and continue until it reaches a major highway. The studied zone is this extension from the square to the highway. Figure 1 shows a plan view of the location of the tunnel and the section which has been studied in this paper.



Figure 1. The plan view of the Amir Kabir tunnel.

The Austrian method, or New Austrian Tunneling Method NATM, was applied to excavate the Amir Kabir tunnel. In this method, an appropriate design is implemented based on the adjacent land from the tunnel and controlled by exact devices. The subsidence is experimentally controlled by regulating excavation speed, completing the casing and facing the excavating surface in NATM excavation. Such specifications have led to the NATM method serving as a suitable option for tunneling engineers.

It should be noted that the NATM is not a specific excavation and support technique. It involves a combination of many established ways of excavation and tunneling, but the difference is the continual monitoring of the risk movement and the revision of support to obtain the most stable and economical lining (Aşçioğlu, 2007).

In this method, it is best to completely excavate the working face leading to a perfect stress distribution. Excavating segment by segment (Figure 2) is necessary in projects carried out on loose land, such as the Amir Kabir tunnel project.

Fore-polling was applied to the tunnel of this study, supported by lattice and dry shotcrete. Moreover, rock bolts were not used in this tunnel. Fore-poling is applied in order to limit the pressure around the top of the tunnel by acting as a pre-supported system, making excavation safe and secure.

Underground water can increase different risk factors in tunneling projects, such as time and cost. In this part of the

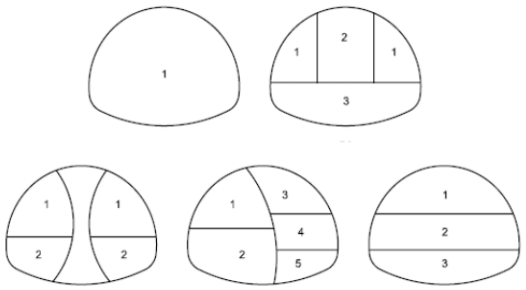


Figure 2. The plan view of the Amir Kabir tunnel.

tunnel, the underground water level is less than that of the tunnel; therefore, the possibility of any water seeping into the tunnel only arises when it is raining or when the water supply is destroyed. As shown in Figure 3, insulation can be used in these cases to mitigate risk and reduce the chance of water seepage into the tunnel (Kolymbas, 2005).

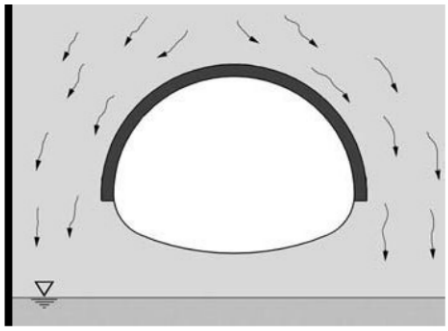


Figure 3. Umbrella waterproofing.

Subsidence is considered as one of the significant negative effects in civil engineering tunneling projects; furthermore, it is essential to control the subsidence that results to structures above tunnels.

Moreover, subsidence depends on various factors, including geological, hydrogeological and geotechnical conditions, tunneling geometry and depth excavation methods as well as the quality of workmanship and management. It is, however, clear that a shallow tunnel will tend to have greater effect on surface structures in comparison to a deep one (Eric, 2006).

In the case of this study, a certain tunnel length is considered for risk analysis purposes. The tunnel diameter is approximately 11 m and the overburden height is almost 9 m. Due to the overburden height, the weight of structures above should be considered in when analyzing subsidence risk. In the considered section of the tunnel, the thickness of the dry shotcrete is 30 centimeters and the final lining thickness is 40 cm.

According to the classification of sands by USGS (Memarian, 2009) (Table 1 and Table 2), a major section of the studied zoned

includes very tiny particles of sand, layer sand, a combination of sand, gravel and much smaller particles, clean gravels and sands with appropriate grain size distribution and mixtures of sand and gravel.

Table 1. Classification of sands.

Major Divisions				Typical names
Coarse grained soils (more than 50% of material is larger than No.200 sieve size)	Gravels More than half of coarse fraction is larger than No. 4 sieve size.	Gravels with fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
		Clean gravels (little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
			GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean sands (little or no fines)	SP	Poorly graded sands, gravelly sands, little or no fines
		Sands with fines	SC	Silty sands, sand-silt mixtures
			SM	Silty sands, sand-clay mixtures
Fine grained soils (50% or more of material is smaller than No.200 sieve size)	Silts and clays Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity

Table 2. Material properties.

Core No.	TP13	TP12	TP11	TP10	**TP9**
Angle of internal (degree)	32	31.9	33.4	32.1	**33.3**
Cohesion (kg/ sq cm)	0.13	0.11	0.14	0.13	**0.1**

RISK

Risk management generally entails an iterative process encompassing risk detection, risk assessment, planning against risk, risk stability and controlling and reviewing the risk (Figure 4). The risk level in any given scenario is defined by the result of the multiplication of the likelihood of occurrence of the risk by its consequence, should it occur (Equation 1).

$$\text{Risk level} = \text{Likelihood} \times \text{Consequence} \quad (1)$$

This paper determines the risks in accordance with time, cost, project quality and operation. Equation 1 can be expanded in different ways, depending on one's needs, in order to identify the risk level and its rating in accordance with its importance and criticality. In order to analyze the risks, weights have to be assigned to the factors being studied: time, cost, project quality and operation in order to increase the risk rating accuracy. The Primary Index Risk formula (Equation 2) and the Aggregate Primary Risk Index (Equation 3) can be applied to rate the risks (Foroughia, 2013).

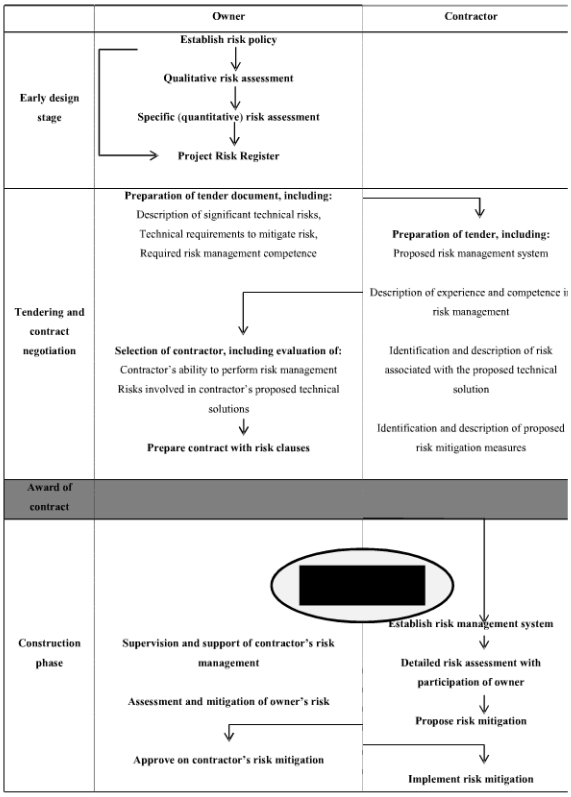


Figure 4. Risk management activity flow for the owner and contractor.

$$PIR = \sum \left(W_i (P.I_i)\right) \qquad (2)$$

Where

P = Probability

I = Level of Influence

W = Weight of the consequence of time, cost, quality and operation factors

(The sum of the presented factors will be $\sum^{4} W_i$)

Such indexes are aggregated using the weighted total average method. In this process, the aggregate primary index risk is calculated for each risk using Equation 3.

$$APIR = \frac{\sum_{j=1}^{m} \left((n_j \times PIR_j) \right)}{N} \qquad (3)$$

Where

M = Expert members

N_j = Number of people in group j

PIR_j = The primary index risk for each one of the risks in group j

N = Total number of experts

For this purpose, a comprehensive questionnaire was designed and completed by tunnelling experts, who were asked to complete the questionnaires using PMBOK and LIKERT standards (shown in Table 3 and Table 4) to determine the relative likelihood of occurrence of the studied factors and their potential consequences. The experts were then asked to suggest new alternatives in order to reduce the likelihood and occurrence of the risks and complete the tables accordingly. It was observed that by suggesting simple alternatives, it was possible to dramatically decrease the completion time and cost of the project as well as increase project quality.

In this research, experts' opinions were collected using surveys and then studied using the Delphi technique, the conference method and brainstorming with a group of seven experts, a group of six experts, two groups with five experts each and another two groups with four experts. Some of the said experts were project managers working on this very tunneling project. As a result of the expert consultation, weights of 0.35, 0.4, 0.15 and 0.1 were assigned to cost, time, operation and project quality, respectively. Table 5 displays the studied risks within this study, the aggregate primary index risk and the alternatives.

Furthermore, some of the alternatives suggested by the experts to reduce the risks associated with this tunneling project included:

- Monitoring and controlling tunnel facing work
- Suitable drainage
- Accurate and exact planning
- Choosing an experienced contractor
- Using experienced personnel and holding training courses for those less experienced
- Wearing helmets and safety gloves
- Using standard machinery
- Precise mapping
- Employing instrumentation and controlling subsidence
- Providing sufficient light in the workshops

Figure 5 illustrates the difference between the aggregate primary index before and after the new alternatives were suggested. Furthermore, Figure 6 shows the dispersion of the aggregate primary index before and after using the new alternatives.

A graph is depicted and risk changes can be pondered only by considering the co-efficiency of P and I (before and after presenting the alternatives) in Figure 7.

Table 3. Questionnaire to determine relative likelihood of occurrence of factors investigated in study.

	Likelihood				
PMBOK	<5%	6% - 25%	26% - 50%	50% - 71%	71%<
LIKERT	Very low	Low	Moderate	High	Very high
	0.1	0.3	0.5	0.7	0.9

Table 4. Questionnaire to determine relative consequence of the factors investigated in study.

Consequence					
Project Objective	Very low 0.5	Low 0.10	Moderate 0.20	High 0.4	Very high 0.80
Cost	Insignificant cost increase	<10% cost increase	10-20% cost increase	20-40% cost increase	>40% cost increase
Time	Insignificant time increase	<5% time increase	5-10% time increase	10-20% time increase	>20% time increase
Performance	Quality degradation barely noticeable	Only very demanding applications are affected	Quality reduction requires sponsor approval	Quality reduction unacceptable to sponsor	Project end item is effectively useless
Quality					

CONCLUSIONS

This paper detected and evaluated 31 risks within the Amir Kabir tunnel project in order to gain a better understanding of the risks involved, and therefore take necessary actions to minimize their occurrence and consequences. Furthermore, performing different risk analyses and risk management techniques has led to a better understanding of the risks involved in the operation phase, hence minimizing the threat to human, environmental and financial resources.

The expert surveys were completed by industry experts, including those who were involved in the design and implementation stages of this tunneling project as well as experts from academia. Therefore, one can assume that the results of this study are as close as reliable as possible given the circumstances. From Figure 5 and Figure 6, it can be concluded that the likelihood of occurrence and subsequent consequences of risks can potentially be significantly reduced as a result of taking simple actions, reducing completion time and project cost while also increasing the project's operation and quality. Moreover, before implementing the actions that resulted in a reduction of the said risks, 60% of the risks were placed in the high-risk category —and reduced to 10% thereafter. Furthermore, according to Figure 6, the highest primary index risk dispersion was in the range of 0.6 to 0.7, which was equivalent to 21%, but was reduced to 3% after using the alternatives to reduce risks. As a result, the highest primary risk dispersion was changed to be in the range of 0.1 to 0.2, which was equivalent to 51%.

The results of this study show that "walls falling down and facing work," "subsidence" and "water entering into the tunnel whilst excavating" have the highest risk ratings after risk reduction techniques have been employed. Therefore, it is essential that tunneling project designers, project managers and contractors pay special attention to these risks.

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Table 5. Studied risks for the before and after alternative designs.

	Risk	Aggregate primary index	
		Before	After
R1	Subsidence	0.78	0.54
R2	Walls falling down and facing work	0.84	0.61
R3	Not having enough information on mapping	0.4	0.3
R4	Not being well-informed from the zone's geotechnical information	0.21	0.11
R5	Water entering into the tunnel whilst excavating	0.44	0.14
R6	Lack of cooperation between employer and contractor	0.80	0.4
R7	The risk of tunnel's water proofing layer being damaged and torn	0.85	0.2
R8	Injury to personnel whilst installing water proofing layer	0.2	0.05
R9	Incorrect installation of armature	0.35	0.15
R10	Injury to personnel whilst installing the armature	0.14	0.08
R11	Damage to excavating machinery	0.55	0.15
R12	Injury to personnel whilst excavating	0.2	0.05
R13	Damage to machinery carrying the materials	0.64	0.21
R14	Personnel injuries while carrying the materials	0.45	0.39
R15	Inappropriate excavating while installing the fore-poling	0.62	0.36
R16	Incorrect installation of pipes in fore-poling	0.67	0.19
R17	Incorrect injection in fore-poling	0.55	0.27
R18	Personnel getting injured while installing the fore-poling	0.15	0.1
R19	Incorrect installation of lattice	0.19	0.13
R20	Injuries while installing the lattice	0.2	0.05
R21	Not having access to practical equipment	0.64	0.32
R22	Wasting the concrete whilst applying shotcrete	0.73	0.16
R23	Unskilled operator in regulating the amount of water in shotcrete	0.66	0.33
R24	Dust	0.57	0.14
R25	Injury whilst applying shotcrete	0.44	0.17
R26	Not supplying materials on time	0.53	0.15
R27	Materials' low quality	0.68	0.16
R28	Delay in concrete production	0.71	0.19
R29	Pumps' failure at the final concrete mold	0.30	0.11
R30	Damage to final mold's jacks	0.47	0.12
R31	Injury to personnel whilst working with final mold	0.9	0.20

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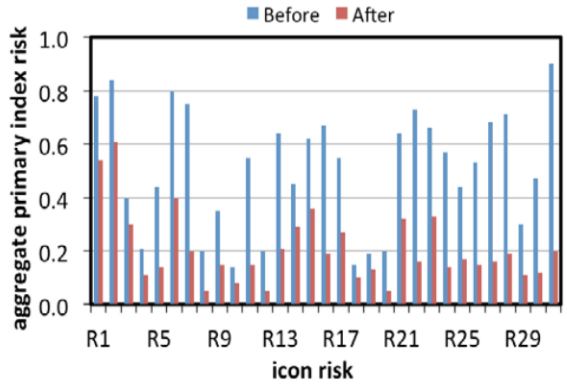


Figure 5. Graph of the primary risk index before and after practicing the risk reduction alternatives.



Figure 6. The primary index risk dispersion before and after a reduction in the risk.

Likelihood	Consequence					
	0.05	0.1	0.2	0.4	0.8	
0.1	0.005	0.01	0.02	0.04	0.08	
0.3	0.015	0.03	0.06	0.12	0.24	Risk Rating
0.5	0.025	0.05	0.1	0.2	0.4	Low
0.7	0.035	0.07	0.14	0.28	0.56	Medium
0.9	0.045	0.09	0.18	0.36	0.72	High

Figure 7. Consideration of the coefficiecy of P and I before and after presenting the alternatives. .