SAFETY RISK ASSESSMENT FOR TUNNEL CONSTRUCTION: APPLICATION OF AHP TO MARMARAY PROJECT

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
OCCUPATIONAL HEALTH AND SAFETY

AUGUST 2019

Approval of the thesis:

SAFETY RISK ASSESSMENT FOR TUNNEL CONSTRUCTION: APPLICATION OF AHP TO MARMARAY PROJECT

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ABSTRACT

SAFETY RISK ASSESSMENT FOR TUNNEL CONSTRUCTION: APPLICATION OF AHP TO MARMARAY PROJECT

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August 2019, 77 pages

Apparently, construction industry has one of the highest work accident rates in the World. While construction industry has many sub branches, each and every one of them has its own distinctives. These variety of projects bring special types of hazards and hazard sources together. Tunnel construction is a very specific area to work on and creating a safe working environment especially for the underground projects is a challenging task.

While confined space works carry different kind of risks, management should be more attractive to create risk mitigation strategies when it is compared with other construction projects. As long as every project has a due date, operations must be completed within a proper time and source management. Risks and hazard sources must be determined. But even the risks and hazard sources are determined and classified, the main objective should be the prioritization of those risks, so decision makers can give required attention for every project risk. While there is limited sources, it is essential to spend them systematically.

This study aims to make a systematic approach to risk prioritisation for tunnel projects. Tunnel construciton projects are complex environments and that is why Analytic Hierarchy Process (AHP) used for the decision making and prioritisation of the risks. In addition to that, interviews have been fulfilled with the tunnel construction experts and derived risk scores for especially on Marmaray Project tunnel construction risks. In the end the risk prioritisation list is created.

To sum up, scrutinizing and combining AHP with experts comments before and during the site executions of tunnel projects can help to create a safe working environment, give enough attention for different risks and using the project sources properly.

Keywords: AHP, Tunnel Construction Risks, Risk Prioritisation

ÖZ

TÜNEL İNŞAATI PROJELERİNDE AHP KULLANILARAK RİSK YÖNETİMİ YAPILMASI - MARMARAY PROJESİ İNCELEMESİ

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Ağustos 2019 , 77 sayfa

İnşaat endüstrisi dünyadaki en yüksek iş kazası oranlarından birine sahiptir. İnşaat endüstrisinde birçok alt sektör bulunurken, her alt sektör kendine özel tehlike türlerini ve tehlike kaynaklarını bir araya getirmektedir. Tünel inşaatı en yüksek riskli faaliyetler arasında listelenen çok özel bir alandır. Özellikle yeraltı projeleri için güvenli bir çalışma ortamı yaratmak zor bir iştir.

Tünel işleri gibi kapalı alan çalışmaları, etkili risk yönetim stratejileriyle hafifletilmesi gereken özel güvenlik risklerini taşır. Riskleri azaltmak için ilk adım, risklerin ve tehlike kaynaklarının belirlenmesidir. Riskler ve tehlike kaynakları tanımlandıktan ve sınıflandırıldıktan sonra, karar vericilerin sınırlı kaynakları göz önünde bulundurarak, etkilerini, olasılıklarını veya her ikisini birden azaltmak için risk azaltma stratejileri geliştirmeye gerekli dikkati göstermeleri için risklerin önceliklendirilmesi gerekir. Bu nedenle, risk önceliklendirme çalışmaları, tünel açma projelerinde emniyet risklerinin sistematik olarak ele alınması için hayati bir adımdır.

Bu çalışma, tünel projelerinde riskleri önceliklendirmek için sistematik bir yaklaşım

önermeyi amaçlamaktadır. Bu amaçla, emniyet risklerinin önceliklendirilmesi sürecinde çok kriterli bir karar verme tekniği olan Analitik Hiyerarşi Süreci (AHP) önerilmiştir. Pratikte nasıl uygulanabileceğini göstermek için, tünel inşaatı uzmanları ile görüşmeler yapılmış ve Türk inşaat sektöründeki mega projelerden biri olan Marmaray Projesi için risk puanları değerlendirilmiştir. Uzamanların deneyimlerini göz önüne alarak Marmaray projesi için geri bildirimler alınmış, belirli bir risk hiyerarşisi oluşturulmuş ve revize edilmiştir.

Bu tezde yer alan AHP ile desteklenerek önerilmiş risk hiyerarşi modelinin, tünel uzmanları tarafından risk faktörlerini önceliklendirmek ve güvenli bir çalışma ortamı yaratabilmek adına kullanılabileceğine ve son olarak, farklı uzmanların farklı şirketlerde bu metot ile sistematik bir risk değerlendirmesi ve yönetimi süreci kurulmasına katkı sağlayabileceğine inanılmaktadır. Bu tezdeki bulgular temel olarak Marmaray projesi ile ilgili uzmanların deneyimlerini yansıtsa da, risk belirleme ve önceliklendirme süreci diğer tünel açma projelerinde de kullanılabilecek genelliktedir.

Anahtar Kelimeler: AHP, Tünel İnşaat Riskleri, Risk Önceliklendirme

To my family..

ACKNOWLEDGMENTS

I would like to express my deepest appreciation to everyone who had taken part in my life and helped me find my path to follow.

I am really thankful for having such a wise and helpful thesis advisor. I would like to express my sincere gratitudes to Prof. Dr. İrem Dikmen Toker. It is a privilege to work with her. She fed me with her wisdom eruditely and also encouraged me since the beginning.

Besides my advisor, I would like to thank Dr. Onur Behzat Tokdemir, Dr. Gözde Bilgin for being in my thesis committee and their precious feedbacks and comments in this duration. Furthermore, I am so grateful to have supportive friends around me. I would like to thank to my teammates, and all METU Falcons Nation, separately, for their thrust and helps in every manner.

Also, I would like to thank my fellow travelers in this world. I am so lucky that I have met with Nikolaj Della Porta Dipinta, and Beatrice Corsorium.

Finally, I would like to express my feelings to my family. Without them, I would have no chance to find myself. I love you all.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
EC	European Council
EU	European Union
SMART	Simple Multi-Attribute Rating Technique
TBM	Tunnel Boring Machine
NATM	New Austrian Method
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
ITA	International Tunneling Association
ITIG	International Tunnelling Insurance Group
DBE	Basic Design Earthquake
SA	Situation Awareness
SF/TF	Shotfirer and Tunnel Foreman
CO	Carbon Monoxied
CO_2	Carbon Dioxied
NO	Nitric Oxide
NOA	Naturally Occurring Asbestos
OS&H	Occupational Safety and Health
TSA	Team Situation Awareness
ALARP	As Low As Reasonably Practicable
HIRA	Hazard Identification, Risk Assessment
P&M	Project Management
OHSAS	Occupational Health and Safety Assessment Series

CHAPTER 1

INTRODUCTION

1.1 Background and Aim of the Study

While the demand for finding alternative ways concerning transportation is increasing worldwide, designers and clients necessitate following construction paths which are quicker and financially feasible also need to find safer alternatives. Regarding that demand on new transportation projects, tunnel construction holds a big portion in the pie. However, tunnel projects are also known to be risky and complex undertakings. There are various hazard sources in construction projects. In tunneling, these sources increase in numbers and their outcomes can have more extensive effects. Working in confined spaces has its unique risks, which include an excess of hazards for all of the parties including rescue teams (Botti et al., 2018). According to EU regulations, every state which is an EU member has to have a proper methodology for risk analysis and mitigation (Borg et al., 2014). To minimize the safety risks, all health and safety utilizations and elements have become crucial parts of tunneling and infrastructure projects. The health and safety programs should be supported by risk information and safety risk assessment is critical to ensure safety (Borg et al., 2014).

This thesis aims to propose a risk assessment approach for tunnel projects. Creating a method supported by AHP to prioritize risk factors and combine these outputs with expert comments and risk ratings. As the beginning, safety risks in tunnel construction projects are derived as a result of a literature survey. Then, knowledge elicitation sessions are carried out with experts to test the validity of these risk factors, especially for the Marmaray Project. A risk breakdown structure is constructed and risk ratings are combined with AHP results to create a risk prioritization table, later on how it can be applied in a real Project is demonstrated with a case study, which is the Marmaray Project.

It is argued that safety risk assessment can also be applied to improve safety culture in construction companies. The conclusions of this study may be adopted to develop effective risk mitigation strategies.

The thesis is organized as follows;

First, risks related to tunnel construction found and distinguished by literature survey then, interviews are arranged with experts and at the same time needed ratings for the AHP simulations are supplied from the experts too. Finally, AHP scores and risk ratings are combined together to create a risk prioritization list concerning the Marmaray Project. In this study, it is applied only on the Marmaray project but as a risk prevention activity, combining these items can be used as a beneficial risk assessment tool for every construction project.

1.2 Tunnel Construction Safety Management and Culture

In every single construction project, creating a safety culture, classifying hazard and risk sources and taking countermeasures is critical for project success. Regarding tunneling projects, every year, confined space work causes fatal accidents and injuries, despite the in force regulatory and standards on such activity (Botti et al., 2018). Most of the time there is a need for a detailed plan for health & safety and environmental issues. The management will provide strong demonstrable visible leadership and commitments towards health and safety programs by personal example and action. The Executives will participate in health and safety meetings, conduct site inspections and health and safety audits, to encourage a positive attitude towards the safety culture. With a proper safety culture, Project management can stay on a proactive phase, which allows the management to block potential hazards before the incidents. In any kind of construction project, there happen to be some other factors rather than human factors. According to Heinrich, most of the accidents are related to the human factors, the ratio on his studies show, 88% of the accidents caused by human factors. Also, Heinrich's studies indicate that 90% of the accidents happen without injuries and 10% of them lead to minor injuries. There are some other important factors to be eliminated rather than human factors too. Until now only the negative sides of underground and confined space works are mentioned in this study on the other hand underground works has some advantages rather than those negative sides, just like the increase in the need for land above the ground during the Project and fewer interactions with environment and wildlife (Barla and Barla 2002).

The safety climate can be geographically sensitive, geological factors affect the tunnel lining and project phases and the determination of the method for tunnel construction directly. Therefore besides the human factors, there are numerous matters to be calculated to create a safe working environment. It is not easy to create a safety culture for any project especially if the project unites many parties and members who will work under the project scope,work-related stress could be challenging in this working environment too (Chen et al., 2017). During and after the construction phase, any kind of settlement around the project zone must be monitored with details. And just like settlements and unit displacements, other project-related effects to the environment must be anticipated precisely in order to solve the problems proactively.

While the project is covered by many types of risks just like the ones related to human and environmental factors, a sufficient risk management program also becomes crucial. Especially before the commencement, risk determination is a must. Using these determinations, management should take measurements and create a risk map, which includes every single risk of the project. Regarding measurements, monitoring and recovering the existing system becomes very important. All this process begins with a risk management phase. These implementations have effects on every aspect of the project. While there is a necessity to find out financial risks and try to avoid their consequences, management must be aware of the occupational and technical risks too. During the identification of the risks and hazards, every factor must be well understood. There are many options to identify the risks just like brainstorming, the checklists or expert evaluation methods. (Dziadosza and Rejment, 2015).

Identifying hazard and risk sources, taking countermeasures and applying these measures to the project is essential for creating a safety culture no matter if it is a super structure Project or an infrastructure Project. While all those implementations and actions have a financial influence on the Project, it becomes a necessity to make an efficient risk analysis and try to create a financial path among those risks. For that reason, there are many theories and methods were improved to be used and take advantage of knowing different safety scenarios and their financial consequences.

1.3 Risk Assessment in Construction Projects

There are many ways and methods for risk examinations. There are qualitative and quantitative methods and depending on the details of the project, a suitable method must be chosen. There are many ways to follow and options to create risk analysis through the construction projects, the right type of risk analyzing method must be chosen between many of the different methods for example, "sensitivity analysis" "event trees" or "Monte Carlo Simulation" (Baloi et al., 2012). For example in Monte Carlo simulation, different iterations are done with the software various times and in the end, the software gives some boundaries for lesser and higher risk situations (Kong et al., 2015).

Multi-criteria decision making methods such as SMART (simple multi attribute rating technique) and AHP (analytic hierarchy process) are also utilized for risk assessment. While there are numerous risks in a project, some of the risks are more common and have a high rate of occurrence. Thus, the probability of occurrence and impact of individual risk factors are assessed and an overall risk score is usually found by aggregation of risk factors. In terms of finding the risk score purposes, a risk hierarchy or risk breakdown structure should be developed. The Analytic Hierarchy Process (AHP) can be used as a tool in complex environments for decision making, just like tunneling projects. AHP can help to prioritize the risks during this study, expert ratings on the Marmaray Project in the scale of AHP between all of the items and risk factors with binary comparisons. After all these evaluations AHP shows which element is more important or more dominant than the others (Saaty, 2008).

As a support to the decision making processes, especially under complicated circumstances and with limited solutions, AHP can lead the way on what is the best solution. AHP uses binary comparisons, with a special rating scale. AHP aims to reprise the elements after all of the calculations. For that purpose, after the score rating, matrices and a series of calculations need to be done. As the final output, weight vectors are observed which shows the importance of each item. These calculations can be done manually or it can be prepared automatically by using some software. Under this study, Super Decision software was used to find the weight vectors.

CHAPTER 2

LITERATURE SURVEY

2.1 Literature Survey on Safety Risks in Tunnel Projects

There is a huge natural variability for parameters which affect the tunnel projects just like, geological/hydro geological/seismic/ geotechnical properties. To create a high level of safety performance, special countermeasures must be taken. Variability of the tunnel projects causes many kinds of risks. To minimize most of these risks, detailed studies on engineering geology/geophysics/geotechnics are required. While proper risk assessment in an organization is a necessity, risk mitigation strategies require to be feasible as well. For example, the cost of such research underwater projects, these costs can increase up to 6% of the construction cost. To have a perception for the tunneling activities, sufficient analyses and comprehensive investigations must be carried out for especially the important parts of the operations just like TBM and NATM phases. In every single construction project, creating a safety culture, distinguishing hazard and risk sources and taking countermeasures is crucial to finalize the projects on time, under the predictable financial expenses. Every year, confined space operations cause incidences that could end up with fatal accidents and laborer injuries, despite current legal regulations and standards related to such activities. (Botti et al., 2018) Most of the time there is a need for a detailed plan for health & safety and environmental issues. The management should lead the way to create a safe working environment, managers should join the site meetings and pieces of training as well to support the safe actions and safety culture during the site executions.

2.1.1 Safety Risk Assessment

To create a safe working environment management needs to focus on many different parameters for every project, when it comes down to prevention and cautions, management should lead the way in all phases of the project even in the design phase.

Many risks can be determined and prevented during the design stage. Of course, creating the safety culture without the participation of all parties is impossible but the management level should lead the way on that task especially by determining risks in the design phase. Safety management relies on how safety measured and these items create the safety culture. Numbers show that organizations with powerful safety cultures tend to have a longer lifetime. But preventing incidences by making the necessary revolutions in an organization is highly related to the management level of the project (Agnew et al., 2013). While making perceptions and preventing incidences are not easy tasks to accomplish, to create a safe working environment, management must be aware of any type of hazard sources. It is crucial to design the project carefully, in terms of both the financial and technical aspects of the work. Some origins of hazards are related to human factors while some others are related to environmental, machinery, financial, etc. sources. Tunnel construction has its way to run construction operations so health and safety issues become more specific. Even the crane operations and ventilation requirements, site safety and check-in requirements must be mentioned in the safety program (OSHA, 2003).

2.1.2 Safety Risk Assessment in Design Phase

Designers shall design easily applicable structures, to abstain from risks by executing some preventions technically in occupational health and safety. The steps to be applied are not limited but may involve the following items:
ii) Finding root causes;
iii) PPE.

Another important method for risk management is to show occupational risks in the drawings itself. To show the risks and hazard sources, risk maps can be prepared. In the case of the design, when phase is completed and if unavoidable risks are detected, they must be mentioned clearly. While every contractor or company needs to work with design information, every risk mentioned on the drawings or technical specifications will be easier to avoid during the site executions.

Any undetermined risk during the design phase should be harmful to the next steps of the project, that is why contractors should do additional risk analyses and try to see all the risks before the construction phase. On the other hand, the best way to prevent those risks is to know them from the beginning no matter as a designer or a contractor. Designers can add other information related to the risks by using additional drawings or additional specifications too.

While there are many types of hazard sources, tunnel construction activities have to face with different types of consequences just like the loss of lives, financial damages, machinery damages, environmental damages, etc. These consequences can be related to financial aspects, time management and health and safety issues directly. As can be seen from many projects, there are direct and indirect causes for the incidences. After the commencement date, management should be aware of all elements of the occupational health and safety for creating safe working conditions to finish the project without any loss. It is important to create safety culture during the operations while giving less impact on environment so the output of the project could stay safe after the construction phase. During and after the construction phase, any kind of settlement around the project zone must be monitored in detail. Just like settlements and unit displacements, other project-related effects to the environment must be followed precisely so problems can be solved before they happen. Regarding this information, selecting the right methods for construction and applying the best solution to the design becomes essential too.

Even for the decision of the tunneling methodology, the designer should consider safety first for all of the aspects. Environmental damages will push the ongoing operations out of planned schedule too. The design shall also consider the relative rates of loading and unloading due to TBM jacking force in both the lateral and vertical directions, and the resultant induced tunnel deformations whether temporary or permanent. Wrong analyses of the soil characteristics could lead to choosing the wrong type of tunneling method, many other problems could occur based on these erroneous choices. Settlements and collapses are the first incidences that come to mind.

Today, risk management applications are not additional pieces of support but they are essential especially for the mega construction projects, risk mitigation also helps to create a better working environment and it also helps value engineering. A very special report from the International Tunneling Association (ITA) was published for that issue too (ITIG 2006, 2012).

Regarding that information, it can be said that construction operations could come up with a variety of hazard sources. Consequences of a construction operation can be hazardous to the people, workers and, the environment. While there is a variety of design methods and risk factors, management should approach all these items wisely while their consequences and effects in different zones at different times during the executions and defects notification period (Titas et.al 2013).

Site operations are complex issues to solve especially during the operations, if any problem occurs and can not be solved quickly, that can damage the project's schedule too. Not only as a time management procedure but risk management before the executions and even design phase can save lives.

If the risks are unavoidable during the design phase, the designer should be aware and at least should put some attention. The Design needs to be safe and feasible. It should help to mitigate the risks, it can not create unnecessary risks (Cash et al., 2015).

2.1.3 Managing Different Types of Risks

To understand the hazard sources better, tunneling construction risks can be divided into major groups. When the risk potentials were taken into consideration, it was more obvious risks with higher potentials and impacts could be classified into clusters which are excavation / temporary support induced accidents, accidents related with geologic conditions, auxiliary works, and contract-related items (Pamukçu et al., 2015).

2.1.3.1 Excavation Risks

When we are talking about excavation risks, we need to consider any kind of landslide risks and risks related to groundwater. Additional to that, if we are considering a TBM excavation, risks are commonly related to; cutter head and keeping cutter head under control, the stability of the tunnel face, how to support the tunnel face when it is needed, immobility of the TBM operator, etc.

The management must be aware of and prevent employers from any kind of hazards so there will be a safe environment to work. For the special operations inspectors should follow the operations and stop the executions when it is needed for safety.

Some important pieces of information before the executions:

- Soil characteristics,
- Underground facilities,
- Existing utilities,
- All plans for the excavations should be done under the consideration of these elements.

2.1.3.2 Temporary Support Risk

When the ground conditions are inadequate, especially during top down – bottom up excavations, some more precautions must be taken too.

When it is considered temporary support, there must be some applications and based on these studies temporary support type must be decided. Site trenches and other safety items are necessary for almost every construction operation, so managers should follow the process directly.

Especially for the urban metro projects, some subsections needed to be constructed, which can be counted as the main construction risk, they can affect the existing roads and buildings easily also good traffic management is needed too (Li et al., 2016). It is obvious from the literature survey and expert's experiences, shafts and other tunnel substructures must be designed properly and after the design phase, during the execution, safety precautions must be taken.

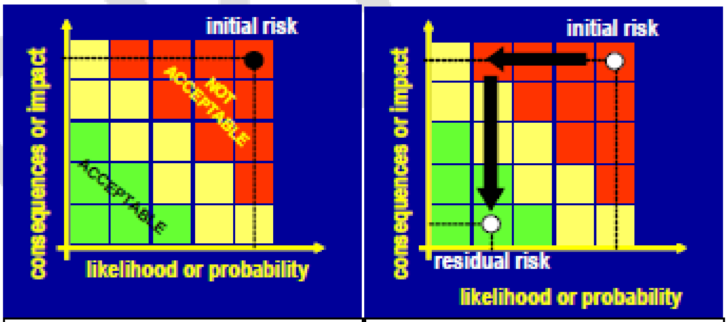
2.1.3.3 Accidents Related With Geological Conditions

Determination of soil and rock masses encountered underground and their geotechnical features are extremely important to prevent most of the accidents. Identification of frequency of discontinuities like faults and joint sets is another important issue. Groundwater can be hazardous to any structural activity too, water table must be confirmed and dewatering operations must be applied when it is needed. Seismic activities must be checked and if the project is in an active zone, there may be needed some extra countermeasures (Pamukçu et al., 2015).

Although tunnels are considered the safest structures under seismic loads, recent studies have shown that some damages have occurred in different tunnels and underground structures during and after earthquakes. To avoid the safety risks related to earthquakes, it is particularly important to perform a risk assessment for special type of structures, effective engineering solutions must be created, from the geotechnical and the structural engineering point of view. The designer must check the safety of the underground structures (including tunnels) to withstand adequately the different applied loads, considering seismic loads, as well as, the temporary and permanent static loads (El Nahhas et al., 2006). By designing the structures under these conditions, construction phases and safe steps to follow the construction Schedule must be underlined too.

The 1999 Duzce earthquake hit Turkey on November 12 and caused damage during the construction of Bolu tunnel. There were cracks around 40 km.

Unidentified risks for the geotechnical aspects could create great hazards for tunnel



Ranges of initial risks.	Residual risks after countermeasures.

Figure 2.1: Probability & Impact Graph

engineering. Some of the risk sources related to the ground conditions; Soil and Soil-like materials;

- High geological, hydrogeological and geotechnical variability, both horizontally and vertically (difficult to predict).
- The possible presence of rock blocks.
- Tunnel mixed - face / Stations walls variable conditions (variable soils, soil and rock blocks)
- The possible presence of pressurized aquifers.
- Abrasive rock blocks and/or soil-soil like materials
- Piping
- Flowing behavior
- Water inrush
- Liquefiable soils Sandy layers inside the alluvium formation, with low overburden, saturated
- Noxious/Dangerous gases (e.g. from buried gas or oil tanks) - Stickiness / Viscidity
- Defective bearing capacity into high deformable ground, with consequent TBM sinking

Boundary soils – top of bedrock ;

- Contact highly variable, with pinnacles and depressions (difficult to be predicted), transition soil - soil-like - weathered rocks -hard rocks from sharp to gradual

- Tunnel mixed - face / Stations walls variable conditions (soils, rock blocks, weathered rocks, hard rocks)
- The possible presence of rock blocks, from weathered to hard
- Presence of pressurized aquifers, included between the above soil deposits and/or weathered rock masses
- Aggressive waters
- Intersection with buried, abandoned wells and/or tunnels, filled or empty, with or without water.
- Flood events, with consequent water inrush during tunnels and station construction.
- Intersection with buried, abandoned pipes or tanks.

These items can be counted as risk factors for tunnel construction, which is related to geological factors.

Proper surveys must be done to see the soil characteristics of the Project area before the operations commencement date as it is mentioned before. In tunneling, the operations which are close to the tunnel portal could be lead to risks for the safety and there may have reserves of asbestos, quartz, radioactive elements, etc (Labagnara et al., 2016).

For example, when we consider the Marmaray Project, a three-stage soil survey was carried out in the Bosphorus (the first of these was the drilling at the preliminary project stage in the years 1985-1987. At this stage, 20 (772 m) soundings were carried out in the Bosphorus. and second stage researches were carried out in order to provide accurate and adequate information to the bidders in 2002-2003. PS logging test, laboratory tests and geophysical seismic reflection and bathymetric investigations were carried out to 10 m rock from the seabed, including a stripped-undisturbed sample and rock core removal at the meter. Following the tender, additional ground investigations were carried out for the detailed design by the selected contractor. The two-stage design earthquake method has been abandoned due to the fact that the structures in the BC1 tunnel route are likely to be exposed to the Function Evaluation Earthquake, which is also likely to be exposed to the Safety Assessment Earthquake twice during the service life of the building. Instead, taking into account the importance of the project and its location, a single-level design earthquake, defined as Basic Design Earthquake (DBE), is envisaged.

These structural performance criteria were searched for tunnel structures to be exposed to DBE;

(a) Damages that occur can be easily monitored and repairable and should not result in loss of function or loss of life.
(b) Immersed tunnel elements and combinations shall protect the water impermeability.
(c) Structures shall remain operable only after a few daily inspections and line corrections.
(d) Repair works should be able to be carried out in a way that minimizes operation.

2.1.3.4 Auxiliary Risk Mitigation Strategies

Auxiliary works can be assumed as different than basic construction works. Just like planning proper ventilation for the underground openings and providing sufficient air for the workers, periodical measurement of flammable and toxic gases and dust that may be released underground is another important aspect for the tunneling works, explosions related with dust must be considered and monitoring must be done against dust. Even there is a low risk for the explosion, explosion vents, and sufficient technical instrumentation must be placed. Periodical maintenance becomes more important to create a safe working environment, transport of materials vertically and horizontally and dewatering operations also can be counted in auxiliary works. Adequate lighting for underground works must be provided and proper insulation of electrical tools must be checked (Pamukçu et al., 2015).

2.1.3.5 Other Risks

As there is more than one type of risk source, when it comes down to human factors, psychological aspects become very important too. In a confined space, workers can easily face psychological problems too. Rather than lighting, air conditioning, creating an ergonomically safe working place there are psychological aspects too. Personnel awareness becomes crucial and tunnel operations highly depend on the situation awareness too. Situation awareness, an area becoming popular to focus and study on, can determine the safety culture of the Project. Historically, the aviation community has stepped forward to introduce the researches about situation awareness (SA) (Durso and Gronlund, 1999). Situation awareness has many subbranches under this concept. Situation awareness is directly related with decision making and especially under stressful operations, awareness determines the success rate of the project. Awareness and short term/long term working memories are other important aspects during the operations, any operator has a capacity and especially the working memory of any person is related with the perception capacity of this per- son too (Endsley et al., 1995). While this is an important aspect for the operational health and safety, management must give focus on how to create situation awareness, how to monitor and measure it so prevention from many incidences related with psychological aspects. For this kind of operations, team situation awareness becomes more feasible.

There can be also another risk source in any project which could come out human and machinery interactions, operators must be aware and well educated so human factors risk doesn't increase with these kind of interactions. Human reliability is a totally different aspect to finish a Project. Human trustworthy is identified, by Neboet et al. (1990), as the probability of occurrences of accidents and the understandable capacities for the errors during the operations. The literature surveys underlined that, human nature is addicted to making errors but this is not an unavoidable task (Dragan, Maniu, 2014).

Rather than any other factor, nationalities and specific risk perception perspectives could be counted to reason of occupational accidents related with human factor. According to a study which was done in Korea, different workers from different nationalities have different rates for probability of occurrence for accidents (Korkmaz, Park, 2017). While different nations have different characteristics in the manner of safety, every single operation and machinery-human interaction should be studied well for the risk factors.

2.1.3.6 TBM Operations Risks

Another risk for managing a tunnel project, which could lead to failing of all project is TBM stuck in accidents. During the design phase, surveys must be done regularly and all cloudy parts should be enlightened by the management, the design will take form from this information. According to soil investigations, soil types of the project region must be determined and TBM type must be chosen in the coordination of these surveys which will be suitable for the related ground conditions.

There might be numerous risks could happen identified with TBM. Risks can be based on drives in weak soil with accentuation to the incidences of squeezing. Crushing ground in burrowing is related to vast misshapen of the passage border and of the passage face and may consequently cause a progression of challenges, for example, staying off the sharper head or sticking of the shield, broad unions of the exhausted soil profile or pulverization of the passage support. These challenges, alone or in blend with different ones, may back off or even discourage TBM activity and, if happening over successive passage interim or persevering over longer segments of passage, may decisively affect the monetary suitability and on the probability of a TBM drive (Ramoni, Anagnostou, 2008). Even launching, retrieving TBM parts into the operation shafts include risky operations. When you consider the weight and sizes of the TBM parts installing and lifting operations become more dangerous. As long as there are different types and ways to follow for the construction activities, variety of risk management approaches needed to be applied with a proper instrumentation. Equipment may be substituted according to actual requirements on the day. All equipment shall be in a fully operational condition with the appropriate certificate by contract requirements. Operational backup equipment shall be available to ensure the safe and continuous execution of the works. All equipment shall be maintained, stored, handled and prepared properly in accordance with the manufacturer's requirements.

It is very complicated to lift and move the TBM parts inside the shafts or other substructures. The assembling team should be experienced and have proper tools and lifting/carrying equipments, on the other hand, the same team must have an operational awareness to prevent the possible accidents, training must be done and all operations must be monitored regularly by the supervisors. Communication during these operations have been underlined by the second expert too. Just like any other construction operation, communication is the highlight issue in the TBM assembling and dismantling operations too. While working with extra large equipments underground could lead several problems, a good risk mitigation can help to prevent those risks. The important thing is the equipment needs to be trustworthy and facilities must be properly set up (Deng et al., 2017).

2.1.3.7 NATM Operations Risks

While this study is about safety in tunnel construction, it is impossible not to get in interaction with NATM method. New Austrian Tunneling Method (NATM) identifies a combination of tunneling methods. As this is the most common method for tunneling worldwide, NATM should be feasible for the project zone too (Clayton et al., 1995). NATM method includes many phases related to each other and completing those steps in a safe working environment depends on a sufficient "plan-do-control-act" cycle just like any other construction project. While the hazards could lead up to damages on the scale of the project, they can go further with environmental damages very easily. So sufficient monitoring and safety management becomes extremely important.

On the other hand, even though NATM seems like the best solution for most of the tunnel projects, on the other hand during NATM operations, many fatal accidents have been reported too (Karakus¸, Fowell, 2004). While just like every other tunneling method, NATM has its own hazard sources, staying proactive and creating an effective health and safety program is crucial for the projects which use NATM too. While occupational health and safety has the monitoring as a highlight material, it is extremely important to choose the right way to risk identification, preventing the incidences and protecting the health and safety of the project by monitoring. Monitoring forms an essential part especially at the geotechnical parts of the projects. With monitoring, risks also can be controlled.

2.1.3.8 Drilling and Blasting Operations Risks

Tunnel excavation will generally be carried out through drilling & blasting with drilling jumbos. The ground support system for the drill and blast sections will vary from place to place, depending on rock mass quality. The tunnel will be excavated using top heading / bench excavation stages, owing to the crosssection of the tunnel and the expected ground conditions.

For tunneling activities blasting is a crucial element, but while it is a key phase for the operations, it brings many hazards with itself too. Flying rocks, different kinds of explosions and toxic gasses can be classified as the main hazardous results of blasting. The threats start to show up in every step of the blasting operations from beginning to finish.

Even during the drilling operations for the charge holes, there are many hazard factors just like; being knocked over, being crushed, noise & dust, rockfall. As it will be mentioned later, the solutions for the related hazards can be clearly seen, there are numerous hazard sources even in the smallest part of the tunneling operations.

Blasting operations are preferable for the hard rock soils and charging explosives could cause incidences too. Falling particles from explosions or boom fallings are some of the hazard sources which could lead the work accidents too. Of course, there are proper ways and methods needed to be followed by the operators, which we will mention later in this study. But like every construction activity, inspecting the site after the blasting is crucial too. Misfires and loose rocks must be checked before and after the explosions too. Proper ventilation, gas and dust monitoring must be supplied carefully. While detecting the air quality for underground operations, there are some items that must be monitored; toxic gasses, lack of oxygen and dust ratios in the tunnel must be checked. There are many different kinds of toxic gasses and CO, CO2 and Radon were mentioned in the study of IHSA too (IHSA, 2017).

2.1.3.9 Hazardous Gas and Dust Risks

As a project detrimental, asbestos can be another example of hazard sources. During the tunnel construction fine particles could be produced (Petavratzi et al., 2005). Natural occurring asbestos releases particulars and fibers into the environment, which could lead to asbestos related diseases, especially for the tunnel workers. Because it is carcinogenic, dust from the asbestos can be assumed as the most dangerous gas during the tunneling activities (Szeszenia et al., 2016; Abelmann, 2015).

These particles related to asbestos have the potential to be harmful not only at the size of the project scale. Tunneling in the areas which can produce asbestos naturally can lead the asbestos related diseases easily (Gaggero, et al., 2017). While this hazard source is critical for both the environmental and safety management of the project, strong monitoring and taking countermeasures to avert the incidences related to asbestos before the occurrences become more than a measurement, it is a necessity. A satisfactory survey must be done to identify the soil characteristics of the project area before the operations begin. In tunneling construction, especially during the operations, most risky place is the portal (Labagnara et al., 2016). When the issues are identifying the project zone; radioactive elements and silica normally show uniform distribution with the geostatistical terms. Asbestos does not act predictably which means it is very hard to determine and follow the asbestos zones (Davis and Reynolds, 1996; Perello and Venturini, 2006).

When the aim is to define the project zone, rather than geological factors and possibilities for collapses and settlements; radioactive elements and silica shows uniform distribution with the geostatistical terms. Opposite to this information, asbestos minerals do have complicated distribution. Asbestos minerals usually distribute highly irregular (Davis and Reynolds, 1996; Perello and Venturini, 2006).

CO is a gas that can be harmful very easily without any footprints behind it. Occupational health and safety education, warning labels, and residential CO alarms can be beneficial. Detectors and alarm systems must be used in every Project with CO risk. Neurological injury is CO poisoning's most common and serious chronic disease (Hampson et al., 2015). Rather than poisoners gas risks, the consequences of fire also have a close relationship with ventilation. The regular operation of a ventilation system is the highlighted material in tunnel safety activities. A strong ventilation system is the must fort hat issue too.

2.1.3.10 Falling From Height Risk

Falling from height or falling on level (tripping/slipping) could be counted as a major risk factor even for underground projects too. Later in this thesis, it will be mentioned how important and common is this type of accidents. While the probability of occurrence is really high, fatal consequences can be expected too. Proper PPE using, sufficient training and good monitoring can help to prevent this kind of accidents.

2.2 How to Create a Safe Working Environment

With a proper safety culture, Project management can stay on a proactive phase, which lets the management block the potential hazards before the incidents. In any kind of construction project, there are some other factors rather than human factors. According to Heinrich, 88 percent of accidents are caused by factors related to human factors. However, there are some other effective factors to be grated other than human factors (Barla and Barla 2002). The safety climate can be geographically sensitive, geological factors effect the tunnel lining and project phases and the determination of the method for tunnel construction directly. So other than human factors, there are numerous items to be calculated to create a safe working environment.

Even the inspection frequencies and specifications should be described clearly by the designer. It is needed for determining equipments and executions costs as well. Rather than daily inspections, there should be some special inspections on the project calendar too. These special inspections are essential for health and safety culture and the reasons behind the inspection rates and ways to inspect must be underlined clearly, this reasoning process is also irreplaceable for financial management. As every inspection and maintenance has its start up costs and techniques, including manpower, material used, testing and monitoring activities. . . etc management and designer should be aware of every single inspections consequences and effects on each and every aspect of the financial basis.

There needs to be a safety hierarchy, between all the parties but as many of the hazard factors could be blocked at the design phase, the designer should have a big control on risk policy and risk hierarchy. Proper risk management must be done according to the main objectives of the project. Designer creates the risk and safety characteristics of the project, gives support to create a safety culture perception, determines the occupational health and safety methodologies for the operations and directly affects the project's executions. For this purpose, for every operation no matter it is the design or execution steps, expertise becomes extremely important. Experts' ideas must be collected regularly and risks can be formed based on this information.

2.2.1 Determining The Risks

While the Project is covered by many types of risks just like the ones related to human and environmental factors, a sufficient risk management program is also becomes crucial. Especially before the commencement, risk determination must be done. According to these determinations, management should take measurements and create a risk map, which includes every single risk of the project which has been determined before. Regarding to these measurements, monitoring and recovering the existing system become very important. All this process begins with a risk management phase. These implementations have effects on every aspect of the project. While there is a necessity to find out financial risks and try to avoid their financial consequences, management must be aware of the occupational and technical risks too. During the determination of the risks, project management can use some tools mentioned before: the brainstorming, the checklists, the experts' evaluation, etc (Dziadosza and Rejment, 2015).

Later in this thesis, types of risks in a tunnel Project and their possible consequences on occupational health and safety will be mentioned again. Risks in tunnel projects can affect the environment as well. A literature survey was accomplished and regarding to data, experts' opinions will be collected. According to expert views, a risk hierarchy will be constituted.

2.2.1.1 Importance of Surveys

When we consider the Marmaray Project, a three-stage soil survey was carried out in the Bosphorus (the first of these was the drilling at the preliminary project stage in the years 1985-1987. At this stage, 20 (772 m) soundings were carried out in the Bosphorus. and second stage researches were carried out to provide accurate and adequate information to the bidders in 2002-2003. PS logging test, laboratory tests, and geophysical seismic reflection and bathymetric investigations were carried out to 10 m rock from the seabed, including a stripped-undisturbed sample and rock core removal at the meter. Following the tender, additional ground investigations were carried out for the detailed design by the selected contractor. The two-stage design earthquake method has been abandoned because the structures in the BC1 tunnel route are likely to be exposed to the Function Evaluation Earthquake, which is likely to be exposed to the Safety Assessment Earthquake twice during the service life of the building. Instead, taking into account the importance of the project and its location, a single-level design earthquake, defined as Basic Design Earthquake (DBE), is envisaged.

These structural performance criteria were searched for tunnel structures to be exposed to DBE;

(a) Damages that occur can be easily monitored and repairable and should not result in loss of function or loss of life.

(b) Immersed tunnel elements and combinations shall protect the water impermeability.

(c) Structures shall remain operable only after a few daily inspections and line corrections.

(d) Repair works should be able to be carried out in a way that minimizes operation.

To meet the requirements outlined in point (a) above, the elasticity of deformations and damages in the structural members should be controlled in the design and the structural elements should be designed to exhibit ductile behavior. As it can be realized with the investigations and technical studies for Marmaray Project, we can assume that client and the contractors tried to stay on the proactive side to prevent any incidences especially related to soil and seismic factors.

As it is obvious, in tunnel construction projects, doing proper surveys before and during the construction operations is a must. Even for technical or any other risks, essential surveying and monitoring can save time, money, lives and Project goals. Surveys are important for creating a safe working environment.

2.2.1.2 Risk Sources

Every risk and hazardous action has a root cause. Risks and hazards can be classified as groups regarding their base where they come from just like; technical risks, human factors risks, risks related with nature. Under this study, tunnel construction risks determined and prioritized under 5 main classifications. For example, when it comes down to human factors, psychological aspects become very important too with this perspective, technical risks and human factors risks have very different bases than each other. Human factors risks have its own parameters, especially the situation awareness, which is becoming a more popular area to focus on and study. Basically, situation awareness (SA) became famous with military issues. (Durso and Gronlund 1999) Situation awareness has many sub branches under this concept. Situation awareness is directly related to decision making and especially under stressful operations, awareness determines the success of the project. As it was mentioned before the attention, short term/long term working memories can be counted as the main items for situation awareness (Endsley et al., 1995).

While this is an important aspect for operational health and safety, management must give focus on how to create situation awareness, how to monitor and measure it so prevention from many incidences can help the organization. For this kind of operations, team situation awareness becomes more feasible. Team situation awareness is necessary for an operation between human to human and human to machinery relations. Exactly in TBM operations, there is an information traffic between the TBM and the operator. Team Situation Awareness (TSA) is a different type of awareness and it is independent from the individuals (Parush et al., 2010). If TSA is not working in a complex environment just like tunnel projects, accidents can come out easily.

As it is shown in the paragraph above there are numerous risk factors in tunnel construction. Some of them have higher risk and could lead to worse consequences. Even those risks are classified under main groups, their effect on each other goes on during and after the construction phase of the tunnel. situation awareness or unawareness is a psychological aspect and this risk can be classified under risks related to human factors, but at the same time especially for the machinery and human interactions, the notion of awareness directly affects the technical risks. Under this study, binary comparisons done with AHP by using Super Decision software support to make the right decision and prioritize the risks according to their importance.

2.2.2 Decision Making and Prioritizing the Risks

While there are numerous risks in a project, some of the risks are more common and have a high rate of occurrence. Within those risks, some of them could have very big effects on both project and the environment. Management should find out those risks before commencement and must create a risk hierarchy. The Analytic Hierarchy Process (AHP) makes binary comparisons and basically helps the decision makers in complex environments to make the best decision (Saaty, 2008).

When classifying the risks, it needed to be mentioned which risks have bigger affects and which could have more harmless consequences. Acceptable risk means, the risk that has been decreased to a level that can be tolerated by the Project climate having regard to its legal obligation and its occupational health and safety policy may have lower effects on the Project. Risk hierarchy arises from this kind of assumptions and perceptions. Other than small acceptable risks, there are also possibilities for dangerous occurrences; an unplanned event, which did not result in personal injury or disablement, but arising out of

1. An explosion of a plant used to contain or deliver steam under pressure higher than atmospheric pressure.
2. Collapse or failure of a crane, derrick, winch, hoist, or other appliance used in raising or lowering persons or goods, or any part thereof, of the overturning of crane / vehicle / equipment.
3. Explosion or fire or bursting out, leakage or escape of any hot / cold Substance (molten metal, liquid or gas) causing injury to any person or any room or place in which persons are employed.
4. Blasting of equipment or container used for the storage at pressure bigger than atmospheric pressure of any gas or gases (including air) or any liquid or solid resulting from the pressurization of gas.
5. Collapse or subsidence of any floor, gallery, roof, bridge, Excavation, chimney, wall, building, excavation or any other structure or formwork or scaffold.

As many of the risks are identified until now, the ways to approach to the risks during the operations must be clarified as well. There are various types of risks and it is very easy to lose focus or priorities in a complex environment while decision making.

To make a proper risk assessment, literature survey is done and tunnel construction risks are basically enlightened. As the next step of the study, interviews will be done to take risk scores from the experts for the founded risk items from the literature survey regarding to Marmaray Project. Experts will give the score for possibility of occurrence and severity of each risk. Experts also will comment on the binary comparisons for the AHP calculations done by Super Decision software. Under these circumstances, finally risk prioritization table will be derived.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Interviews

As the main objective of this study is to focus on to the risks related with tunnel construction, than assume that these risks belongs to a big tunnel project just like Marmaray, by using AHP with support of Super Decision Software and to get the final results to manage the risk prioritization period, for the beginning there need to find some data from experts.

As the kickoff, experts have been searched and find. During this search, especially tunnel experienced experts were chosen. Three experts have been found to make interviews. Experts' qualifications and other personal information have been mentioned under the interviews. After finalizing the search for the experts, interviews have been accomplished. During the interviews, questions and risk factors for a tunnel projects have been shared and asked experts. All the questions for the risk factors were derived from the literature surveys and expert suggestions.

To create a proper safety risk breakdown structure, expert interviews have been done. While this study focuses on occupational health and safety on the tunnel construction industry, experts have been chosen from tunnel engineers. For every single project, the contractors must complete their hazard analysis and risk assessments and identify appropriate actions that are superior and feasible to reach risk mitigation goals. Project managers and engineers must follow a way of codes and regulations, while following this path, experience plays a crucial role in the decision making activities too.

3.2 Interview Details

The first expert has more than 14 years of experience in tunnel projects. He has worked under metro, sewerage line, dam and TBM tunneling construction projects, he has been working in an international company now as Tunnel Projects Coordinator. While many of the risk types and classes were mentioned in our list for Marmaray Project, he added more items as construction risks. In the interview it is also mentioned by the expert; contractor's site management, managers, and supervisors shall cooperate with and participate in scheduled H&S inspections, audits and assessments. Whether conducted by the contractor, the Employer or regulatory agencies.

Expert's answers after the questions of what kind of risk assessments he has been using during and before the execution of the projects were simple but detailed types of risk matrices.

The second expert is a civil engineer too, he has more than fifteen years of experience. The results of this interview show that both of the experts gave the highest scores to the risks related with human factors, while the first expert's risk scores are lower, the second expert's highest risk score is 16(nine different risks have that score). Especially lack of inspection risk score becomes crucial to understand, both of the experts are more aware of the risks related to supervision and risks based on human factors. They both have an aim to focus on human factors risks. Regarding all these datas, as both of the experts mentioned risks related to human factors detaily, these kinds of actions should be taken before and during the executions wisely. Also, both of the experts have mentioned that traffic rules and regulations must be strict on the construction site. Otherwise, it is impossible to avoid traffic accidents.

The second expert has used a 5x5 risk matrix to understand the project risks, he has been working in a tunnel construction company too. He basically focuses on to construction site set up operations, creating a habitable environment for both blue collars and white collars. Because of his experiences, he gave some examples about the effect of food poisoning to the construction operations. These kinds of mishaps could affect more than one person in any construction site. Also, water resources must be checked and monitored regularly too.

Generally expert one and expert two have some similar answers, while expert one is more sensitive to the CO risk, expert two is more aware about the TBM related risks. Both experts are experienced in tunnel construction, both of them have been worked under metro projects and used TBM-NATM methods. Human factors, reliability, human - machinery interactions are emphasized by the first and second experts. Basically all these items are related with human factors.

Expert number three has experience for 7 years. Not like other two experts, this expert gave the highest risk score to the TBM related risks. Also, it is shown in risk breakdown structure, risks related with the construction phase have higher risk scores than risks related with human factors. While the first and second expert has focused on construction site transportation and traffic risks to add into the risks breakdown structure, expert number three mentioned about open shafts, crane inspections, vertical horizontal transportation and food poisoning.

Expert number three especially has underlined that, there is a tight relationship between durability and safety. Structural failures primarily due to static and fatigue lots. Transportation of big machinery through shafts, especially in tunnel projects can be extremely dangerous and according to experts' experiences, these operations must be supervised wisely.

All of the experts are well experienced in construction industry, all of them have worked inside and outside of Turkey, which means they have a wide safety perception beyond one country's rules and regulations, they have experienced similar scenarios in and outside of the Turkey with working teams more than one nation.

Some safety risk factors have been identified and asked experts to give scores about the possibility of occurrences and the severity of related actions. Risk factors have been classified under five main groups; Technical Risks, Risks Related With Nature, Human Factors, Construction Risk Factors, Management Risks. Under these five main groups of risks, there are some sub branches, under these clusters. Risk probability of occurrence and risk severity factors scores have been given by the experts. Technical risks are mostly about TBM/NATM, excavation risks and other structural possible risks related to tunnel structure. Ventilation system based risks are also covered under this item. Risks related to nature contain risks which have really high severity according to the expert interviews. Landslide, earthquake, poison gas, groundwater risks are counted as the main risks on the table. Project management should establish the main risk factors that influence the tunnel which is in close contact with the environment. For the risks related to nature, risk analysis and surveys must be done by the management. Risk analyses of a tunnel construction project include extremely important steps and qualitative and quantitative methods may be needed (Shuping et al., 2016). In tunnel projects, it becomes more crucial to catch the determined dates and schedule because as it is not a superstructure project, it has more parameters which could have bad effects on the executions, said expert number two. Existing utilities, existing structures, permissions and even archaeological findings could lead to traumas that can delay the all steps of the process. While there are too many risk factors for possible delays, management is under a big pressure to catch the determined key dates right on time. Expert number two again underlined; just like any other risk factor in a tunnel construction project, there are some good and some bad ways to solve every problem and prevent the risks to catch the key dates and finish the project right on time. The management level must be well organized. Expert number three said, increasing the working hours and shifts to finish the project right on time is not a management level prevention.

Different experts have different risk perceptions and different experiences, so experts' answers are different from each other. In this study, experts risk scores for Marmaray and literature surveys about these findings are given. Risk breakdown structure was created according to these findings and it was asked to the experts to give some more examples if they have ever lived any hazardous situations, if they have ever faced off any risk which didn't appear in the related table and which was set according to literature findings. It has been kindly asked to add those risks too. According to experts' answers, new items added on the risk breakdown structure.

After the completion of interviews, three risk breakdown structures were procured for each expert. These breakdown structures involve risk items under five main risk groups for tunnel construction projects as separate nodes. Every risk item has two components; probability of occurrence and severity. Both of the components had a scale for rating from one to five according to low to high effect.

Finally, the research methodology followed in this thesis is presented in Figure 3.1. As can be observed from Figure 3.1, after the knowledge elicitation process, an AHP-based application will be carried out in the following sections.

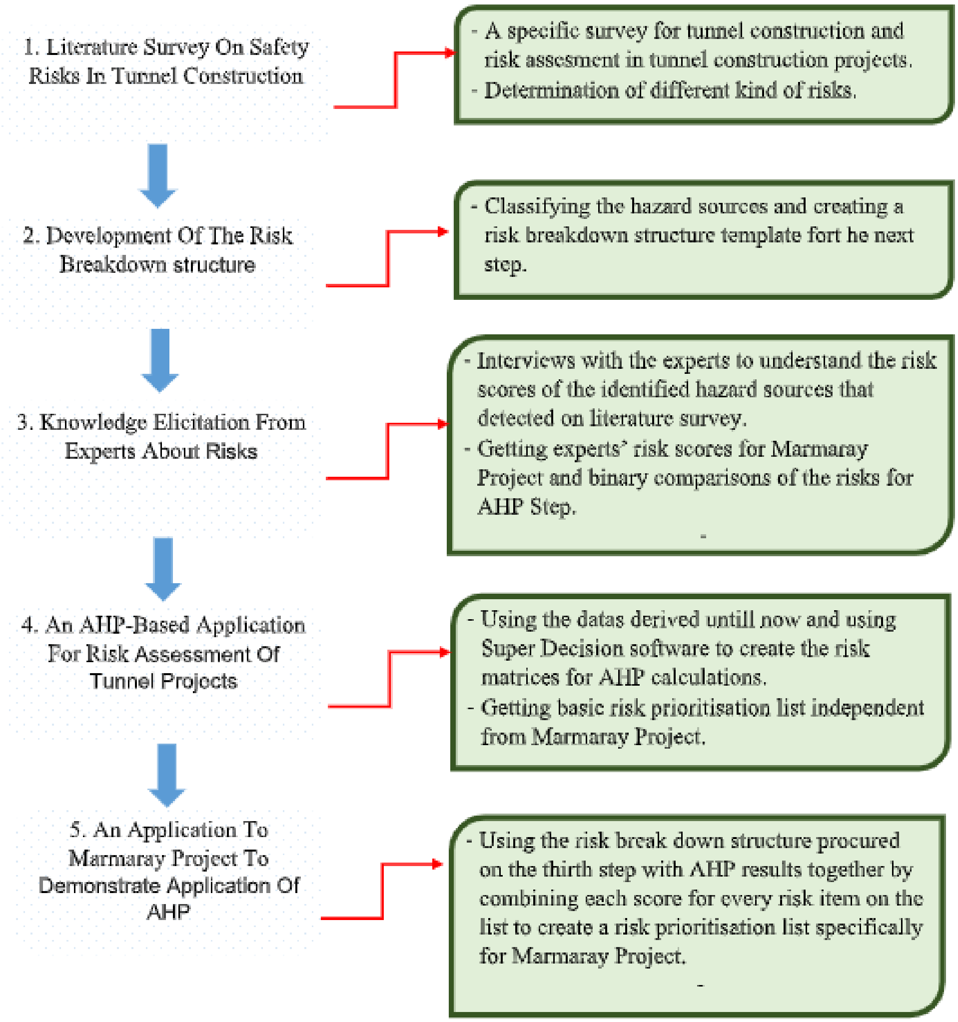


Figure 3.1: Applied Methodology

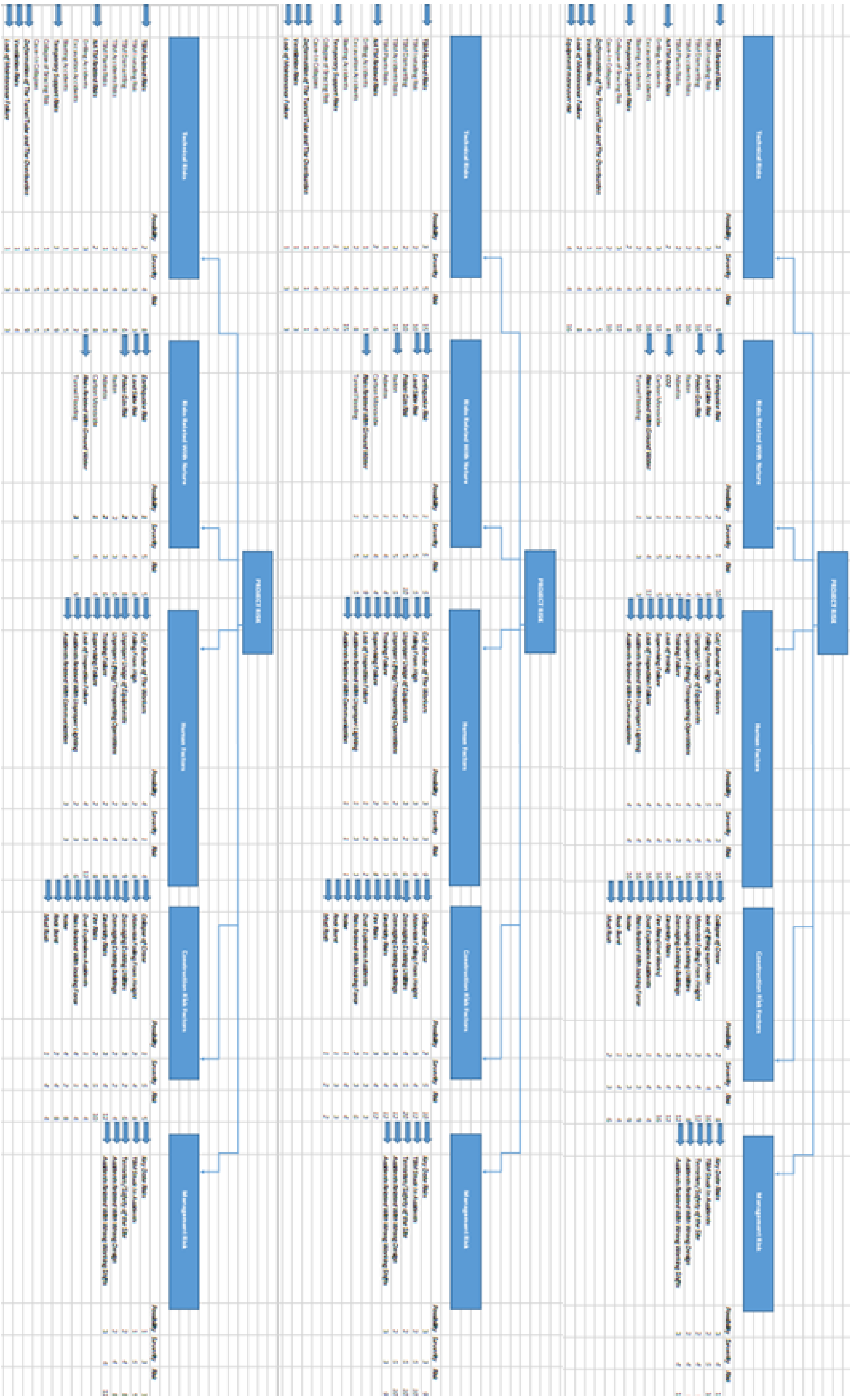


Table 3.1: Experts 3-2-1 from Left to Right

CHAPTER 4

A BRIEF INTRODUCTION TO MARMARAY PROJECT

4.1 A Brief Information About Marmaray Project

Marmaray Project is an intercontinental rail system project that will connect Gebze on the Asian side of Istanbul and Halkalı on the European side with different construction structures. The Marmaray project is one of the most important arteries of the Istanbul Metro network, which has been expanding since 1985, exceeding the 76 km distance between Halkalı and Gebze with 37 above ground and 3 underground stations. British Standards and OHSAS 18001 standards are applied in all aspects of the project from beginning to end of the project.

Figure 4.1: Marmaray Project Route

British Standards and OHSAS 18001 standards are applied in all aspects of the project from beginning to end of the project.

4.2 British Standarts

Tunnel construction covers the safety principles that are applied in the construction sector. Throughout the projects, companies work in accordance with a Health and Safety Planning that was established at the beginning of the project in terms of safety and health. British Standards helps to create a healthy and safe working environment. The aim of Design Management Regulations 1994 is to ensure that all branches work together to avoid hazardous OHS situations. In the detailing of the project, the risk assessment reports emphasize the places where precautions should be taken in terms of security according to The Contractor Design Management Regulations 1994.

4.3 Integration of Design and Construction

It is more critical to create a safe and healthy working environment in the under ground works compared to other construction works. It should be a reliable and continuous engineering during planning, exploration, design and construction. Just like mentioned before in this study, during the design phase, many tests performed and design elements improved according to the results of these performance tests.

On the other hand, Marmaray Project has many special parts just like immersed tunnel sections which requires different design principles.

4.4 Education

According to the law, Marmaray employees have to be trained against possible risks. Some other personnel, such as operators, receive additional training in their respective fields. The scope of the trainings;
-Possible hazards
-Safe working methods
-Land rules and prohibited activities
-Using protective equipment
-Working in liaison for safety and health

- Special exit from underground study rooms in emergency situations

4.5 PPE

A good health protection can be made by identifying risks and hazards. These risks should be taken under control. PPE solutions can be counted as the last methods. According to Marmaray HES plan PPE using;
- Head protection (helmet). (BS EN 397)
- Foot protection (steel toe boots). (BS EN 344-1)
(Gloves should be worn up to the elbow during grouting.)
- Eye mask/glasses.
- Protection/whole body.
- Protection of the respiratory tract. (Hazardous substances should be vented in risky areas. The last resort should be to use protective equipment to protect the respiratory tract.)
- Easy to wear visible clothing (BS EN 471)
- Ear protection. (HSE Publication L (08 [6a]))
- Everyone is obliged to protect himself while working under ground.

4.6 Fire

In July 2011, impact tests were performed in Effectis Nederland laboratory and fire tests of TBM tunnel sections. According to Effectis-RWS procedures (2008 Effectis-R0695), these tests were carried out on a representative tunnel section. These tests excluded three points;

i) The swelling effect of concrete that may occur in anchors in immersed tunnels.
ii) The swelling effect of the concrete that may occur on the anchors in the TBM

tunnel.
iii) The maximum temperature that may occur between the two CPC segments.
In this report, these three elements are explained by finite element method and some thermal calculations.
2011-Effectis R0855 [Rev-1]. In addition, some adaptations have been made due to air gaps that may occur in anchors and fire protection materials.

General Comprehensive Analysis Anchors and rubber gaskets were calculated by DIANA v.9.4.3 (BC1) Modeling based on the design drawing of TGN. Only the worst scenarios were considered thermally. The materials specified by EuroCode were used (1992-1-2 (steel), 1992-1-3 (concrete))

4.7 Marmaray Project Importance of Risk Prioritisation

Until now literature survey for tunnel construction risks were identified and Marmaray project safety measures were mentioned. Marmaray is a unique project with it’s location and different structural components.

In this study all these risks from Marmaray project aimed to prioritised under the light of literature survey and expert interviews.

CHAPTER 5

INTERVIEW FINDINGS ON RISKS IN MARMARAY TUNNEL PROJECTS

5.1 Interview Findings

Expert one has mentioned a workplace with limited openings for ingress or egress making it difficult for the person inside the confined space to escape freely at will. This workplace could be oxygen deficient or oxygen enriched which is quite interesting, and could have (i) Restricted flow of fresh air, (ii) or contain (a) inflammable gases / vapors (b) or toxic gases (c) or other specified physical hazards which could overcome those working inside the confined space and physically or mentally immobilize the affected person. Especially CO was highlighted during the interview by the expert, because it has not an obvious scent, it becomes highly fatal. Suggestions were given by the experts to monitor especially the CO during the construction stages. Many types of risks related to poison gases can be detected during and before the construction activities but even with small mistakes, consequences can be fatal. The contractor shall be aware of air conditioning and respiratory measurements for air quality which is acceptable to the employer, whenever a respiratory system hazard exists.

Another very important issue for the first expert was working shifts. According to all his experience he decided that in a construction project, arranging working shifts more than 8 hours causes occupational accidents, the risk of having an accident under 12 hours shift is much higher than 8 hours shift. Every minute after eight hours creates new risks. The management should lead the way for a safe working environment as it was mentioned before. It is not enough to organize shifts according to 8 hours for the workers for only main contractor company. Subcontractor and vendor companies must be checked wisely about working conditions and working shifts as well.

Accidents related to temporary supports and scaffolding has been also mentioned during the interview by the first expert. Scaffolds, working platforms and other types of temporary supporters should be inspected periodically and wisely by the experts. Working Platforms may be made from normal tubes or fittings or from proprietary component systems. All temporary works design drawings and calculations should be checked and approved by a professional engineer to determine the appropriate type of scaffolding to be erected.

The first expert also shared many experiences too. After a 20 kilometer metro project, while there was no death record during the project, on the last day, only fatal accident has happened and one worker died. When root causes of this accident are discovered, there were some main obvious reasons. First of all transportation operations always have big risks no matter they are vertical or horizontal. On the other hand, rather than technical risks, when the date of the accident is realized, it can be shown that there was some carelessness too. Because that was the last day of the construction operations, workers lost their awareness about the environment and operations got decreased. The contractor should be aware about all of the subcontractors, not only his own employers. The awareness level of every worker on the site must be checked regularly too. Independent from the project phase, situational awareness is a must for all workers and supervisors. Otherwise every project can be finalized with abortive results.

Mainly the first expert gave higher scores to the risks related to human factors. He mostly defended the opinion of proper supervising and training can block many risks before they have a chance of occurrence. Which made his statements consistent because as it was mentioned before, he mostly gave the highest risk scores to the risks related with human factors. And proper supervision and sufficient training are the methods that are using to eliminate the risks related to human factors. He also mentioned about "Lessons Learned Register". According to his experiences, the contractors shall monitor and record in a register all lessons learned from the successes and failures experienced throughout the duration of the project execution. Human factors based risks are the main reasons behind hazardous accidents. That is why, focusing on human factors related working accidents can be beneficial for the projects (Xie et al., 2018).

According to his opinion, while highest risk related to natural factors is tunnel flooding risk with a score of “9”, he found electricity risk has a score more than this value.

Falling from height risk has been founded as the most risky item on the list. The expert gave “8” as risk score for this item. Even the projects going underground, there are still some operations which require scaffolding, so there is a potential for falling from height risk for these operations. One of the most fatal accidents in the construction industry is falling from height and even experts are in the same idea too (Burke et al. 2011).

The first expert also gave some advices about the blue collar workers, how much they have an aim to live a work accident related to their personalities, nationalities and characteristics. Basically, every country and every nationality have their own risk perception ways and awareness factor is also changing regarding to experience, education, age...etc. All of the risks and hazard sources could be more effective on younger workers. Young and unqualified workers are sensitive groups according to occupational accidents. Just like the apprentices, it is also a fact that young skilled workers are more sensitive to accidents and illnesses during the construction operations who have inadequate experience. For those vulnerable classes, young workers should not be classified in many of the differentiating just by their age. Different groups show different weaknesses against occupational safety and health risks. Managers and engineers need to consider this complexity in education too, specific training sessions are essential when performing risk management or site executions (Hanvold et al., 2018). Occupational health and safety(OHS) vulnerability generally focused on identifying sociodemographic items or occupational specific groups with more occupational accidents rates. Worker empowerment to attend in injury prevention refers to a worker’s ability to attend in health and safety, communicate with employers and site managers, asking questions about identified workplace hazards, and if it is necessary to refuse unsafe duties (Yanar, Lay, Smith, 2018). As it is discussed, site executions are highly related with blue collar workers, occupational hazards and risks have different effects on different worker groups according to the suggestions and remarks of the first expert. There are also valuable studies in literature based on the idea; ohs groups are specific and have different characteristics regarding to their nationality, age, experience etc. . . Different groups require different efforts, training and even PPE. In different countries, rules and regulations are varying too, that also triggers the working groups to diversify.

The second expert mentioned about material transportation problems. It can be both vertical and horizontal transportation in the site and transportation in all manners can be hazardous, a proper risk determination before all the transportation operations must be done precisely. Other than lifting operations traffic in site can be dangerous too. The second expert gave some examples of accidents has a root cause related to transportation of materials. Traffic-calming measures should be signed and obviously visible. Signs can be lit or made reflective. While placing the traffic-calming features management must be careful, because they can sometimes increase risks. Just like other safety devices, the second expert also suggested speed humps. Speed hump warning signs must be visible, and there should be enough distance between the hump and the sign to allow drivers to decrease their speed safely. The humps themselves must be marked too.

The second expert highlighted that a mobile crane works on the basis of balancing over-turning forces so it is potentially a dangerous hazard source for tunneling projects too. The crane operator must understand the advantages and limits of the equipment that he has been working on.

Expert two shared his experiences and measures which he had applied before on transportation management in the construction site too. All vehicles like crane, truck, transit mixer, trailer, Hydra, JCB etc shall be allowed to move at the site only after ensuring fitness of vehicles by P&M in-charge and safety team. P&M in-charge and safety team shall make a report on the prescribed format. Only licensed and experienced operators or drivers shall be engaged for driving vehicles. The hired vehicle shall also be subjected to fitness certification by P&M safety personnel. Necessary clearance shall be obtained from the local authority as well as client for diverting traffic or using the road for plying heavy machinery. Which is extremely important because there may not be a good traffic environment around the project site, even traffic rules are close to each other in different countries, traffic behaviors and risk perceptions are different for different countries. Speed breaker shall be made on road passing along the worksite. Breaker shall be painted properly and reflecting warning signs shall be displayed. Only authorized personnel registered with P&M Department are permitted to operate motorized equipment. Operators shall have a valid operator's license. They shall be seated inside the vehicle body when in transit. All vehicles shall be parked at the area designated except vehicles in use for construction work. Narrow roads are to be opened at all times for access. Trucks and other transport equipment shall be constructed to prevent material from falling off onto the road. Any material displaced shall be removed from the site immediately. Proper clearance from the local authority shall be obtained for road cutting and necessary diversions shall be made accordingly. Traffic movement shall be stopped while heavy material shifting by crane. Area In-charges shall make necessary diversion.

Expert number three and two mentioned food poisoning. All of the experts have an awareness about the risks of material transportations in construction site. Especially expert number three shared his experiences about food poisoning in construction sites, while trying to manage a project in foreign countries. While transferring workers to the different countries for specific operations, management must be aware not only about the working permits, it needed to be considered workers are human beings and they can be affected by many parameters just like socio cultural differences, climate changes, epidemic diseases,. . . etc. Food poisoning is one of these factors it can be seriously effective for the sites which are away from civilization. Expert number three suggested to find safe food supplier, which has related certificates and if it is possible do some random checks and take some samples from the food to control. Especially in hot weathered countries, cold chain must be well understood and it shouldn't be broken. Keeping the food safe and healthy is totally another engineering and there are many different ways just like different kinds of refrigeration systems to use especially in big construction sites. (Adekomaya et al., 2016) While controlling all these processes is a big work and responsibility for project management especially for projects where the contractor doesn't have an experience, according to third expert it will be clever to find a subcontractor or supplier for all these food supplying works.

Opposite to risks related to nature human factors based risks have higher possibility of occurrence rates in the eyes of experts. Mostly lack of inspection and cut/bruise injury possibility rates are higher than the other items under human factors risks. Human factor risks could have so many items, it can be also related to many reasons physically and psychologically. While many of the risks can be prevented by the precautions taken by the management, there are some special items under the management risk in the interviews, which have a direct relationship with the management. So far we could say that occupational health and safety have to stay with the same path with the construction operations, extremely rigid precautions and stopping the site works because of safety issues will ruin the Project Schedule. All three experts were in the same idea, work must continue in a safe environment, and Project Schedule and key dates must be effected minimum during the construction phases. Management can change the shifts and working hours of the workers and that increased working hours could give a chance to finish the project right on time but these shifts can be dangerous for the workers, exaggerated working hours will lead injuries and accidents especially in tunnel projects. Expert number two said he was extremely sensitive about working hours and shifts during the projects, regarding his experiences when management increases the working hours or put some extra shifts, accidents become unpreventable. Prolonged labor also affects the free time of the workers, they can not rest enough and the psychological factors always put them under stress (Yu et.al 2017). Within all these informations above, it is more understandable why expert number two has mentioned that extending working hours or shifts could lead more trouble on the way to catch the key dates to finish the project right on time.

Expert number one has mentioned a TBM stuck in accident in Bangalore, India. In this case, the contractor should get in contact with the material supplier as soon as possible and study on the construction geology again. Despite effective signs of progress in the advancement of shielded tunnel boring machines (TBMs), the use of these machinery through weak soil types and adverse geological conditions is still risky. Meanwhile, the excessive convergence of loose soil and week ground under high in situ stresses can show high levels of load on the shield, which makes the machinery sensitive to entrapment in weak rocks, especially under large overburden. The consequences of these items return as high costs on tunneling companies (Farrokh and Rostami, 2008).

Geological surveys are extremely important, but these surveys do not always enlighten every single aspect of the project. At the same time, even it is an extra large powerful machine, TBM can be damaged too (Willis, et.al 2018). Expert number two also added these facts about tunneling projects; when preparing for a tunnel project, first issue is to check the design and redo the surveys if they exist, if there is no survey has been done work start with the survey phase, once contractor knows the soil profile now design must be completed. Regarding to that design, TBM type will be chosen and get in contact with the manufacturer companies, as it is a unique Equipment manufacturers are limited. The contractor may prefer to order a new TBM or refurbish an old one. Either way, it will take months to prepare the TBM in the factory and transport the equipment to the site. After transportation as it has been mentioned before, installing TBM operations will take another time of months. So even with this undetailed explanation, it is obvious if any major mistake happens with TBM just like stuck in accidents because of the wrong type choosing, that accident will have catastrophic consequences for project's life cycle, while it is impossible to talk about safe working environment when there is no work on the site, TBM and other site operations should go on regularly. In the bad scenario if the TBM stuck accident occurs, it will be more costly to rescue the existing TBM. Under the light of all these informations it makes sense TBM stuck accident has a low probability of occurrence but extremely high rate of severity.

Rather than technical risks, there are various types of risks which are independent of technical issues. While the globalization becomes a necessity, contractors face with bigger challenges in tougher countries and locations. Terrorism is one of the most important risks which have a high possibility of severity. Especially expert number three has been mentioned that, contractor should determine the risk of terrorism for the works before suffer any effort during tender process. Expert number three also told terrorism is not only related to the construction site, it also affects the sources and economics of the country where site executions go on. Terrorism has wide effects on nations and countries. Even for marketing and transportation of goods become extremely complicated in this kind of nature. It is getting harder to find equipments for each and every operation, evidence from various countries and markets underline that terrorism has multiple effects on markets (Arin et al., 2008). Even for our experts, terrorism has direct and indirect consequences on the works on site, related precautions must be taken even for the bombs and other weapons, entrances should be taken under control by the professionals. But on the other hand there are some other risks related to terrorism which have an effect to every part of the project, that is why experts focused on this issue in two different ways.

According to our questions and experiences of our experts, wrong design based work accidents can be harmful too. Notwithstanding the big developments in new technologies just like industry 4.0, many different accidents could come out from human and machinery interactions (Moura et al., 2015).

Another extremely important issue which was mentioned by expert number two is detailed drawings which show the danger zones. If the risks and hazard sources are highlighted on the projects, it becomes much more safe to work and execute the operations, expert number two told these applications will decrease the possibility of occurrences for that kind of risks.

CHAPTER 6

USING AHP FOR SAFETY RISK ASSESSMENT

6.1 Using AHP for Safety Risk Assessment

Analytic hierarchy process (AHP) is very popularly used tool to operate multi criteria decision making problems. While Analytic Hierarchy Process has some boundaries, within different parameters, decision making independently is one of its abilities. It was first studied by Thomas Saaty and just like the situation awareness, it mas mainly used for military services (Butdee, Phuangsalee, 2018). Basically AHP can help to priorities the risks and in complex environments decision making process could be assisted by this item even for the subjective and objective aspects. AHP tries to find out the best option/decision between many different ways. The AHP constitutes a rate for every determination criterion depending on to the manager's or decision maker's binary comparisons about the criterias. All of the options and determination criterias are identified by the users that is why AHP is a flexible method to use.

6.1.1 AHP Calculations

AHP determinations can be based on the experiences, on the other hand this tool has ability to convert the determinations made by the decision maker into rankings which have multiple criterias and it is independent from if the evaluation is qualitative or quantitative. While single calculations are easy with AHP, there may need to have a lot of calculations for the decision making process. AHP could be applied to any system manually. Analytic Hierarchy Process, written by Russell and Taylor tells, that is an effective and quantitative method which can be used in complicated situations and environments to give the best decision. It has phases to develop numerical ratings between every risk item under this study and combination of these rankings will give the risk prioritization list on the final step.

6.1.2 Fundamentals of AHP

The objectives (sub-objectives, if any) are to determine basic criteria and alternatives, and define them in a hierarchical order, primarily for purposes, and to conclude by comparing the criteria and alternatives. AHP has three foundations. These are the formation of hierarchies, determination of advantages, logical and numerical consistency. By creating a hierarchical order, the purpose, criteria and alternatives are determined. All parts in this order are interconnected. It is easy to see how changes in any one will affect the order. In decision making, a lot of data combined together in this way and comparisons can be made between different parts. In this order, the advantages (most importantly, the most suitable) are achieved with certain operations. These operations should be logical and numerical consistent. With the help of a nominal scale, the elements forming the hierarchy are compared in binary way. Comparisons are used to create a fundamental matrices. The mathematical operations and the various elements of the hierarchy include the eigenvector of the matrix. The eigenvector is used to assess whether the consistency ratio of the comparative matrix is reasonable.

AHP has some simple steps to lead the decision making. First step is defining the problem, AHP defines the problem and determines the kind of knowledge sought. Establishing binary comparison matrices is the second step. Third and the last step is calculation of significance value of all alternatives individually. As it is mentioned before classically all the calculations can be done manually.

In general, the content of AHP methodology is described above. The application steps can be assumed like (Kamal, Subhi, 2001);

1. Identification of the problem and determination of the the main objective
2. Placing the criterias.
3. Binary Comparisons (Saaty, 1986: 843).

4. Evaluations of the matrices
5. Calculations of priority vector matrices
6. Calculation of weighted total matrice
7. By dividing the row total values in the weighted total matrix by the priority matrix row values obtained in Step 5 and taking the arithmetic average of the values in the last matrix of the resulting (nx1) dimension. calculation of value.
8. Calculation of consistency index The consistency index is calculated as follows; (Saaty, 1993).

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

9. Calculation of the consistency ratio by using Table and CI The randomness indicator should be used from the mean randomness (Saaty, 1980). CR = CI / RI
CR: Consistency Indicator
RI: Stability Indicator
11. Calculation of the final priority value to be achieved by multiplying the criteria priorities calculated on the basis of criteria with the priorities obtained as a result of a pairwise comparisons (Kapar et al., 2013).

Calculating the CR value can be problematic. It has an aim to be more than 10% in complicated environments, according to some studies even more than 80% of the CR values had an aim to be more than 30%. (Goepek et al., 2017).

Experiences in the literature show that, CR > 0.1 is not very important and critical depending on the project structure and type. As long as there are reasonable weights for CR 0.15 or even higher (up to 0.3), depending on the number of participants (Saaty, et al., 2003).

6.1.3 Using Super Decision Software for AHP calculations

As long as the ability of AHP has this power to make the decision making process easier, there are some other tools and software will be discovered too. After determining the criteria and subcriteria, by analyzing the interactions between the items, after determining the criterias that effect each other by using the Super

Decisions program, intercriteria links, internal and external dependencies, and feedbacks can be determined. Super Decision program have different versions and it helps to priorities the items for the decision making process. After transferring the data to the Super Decisions program, unweighted super matrices, weighted super matrices and limit matrix are obtained respectively. Then the priority values of the criterias in the model are reached from the result screen of the program.

Mostly data can be observed from the experts to see the differences between the items, basically within the scale of 1-9, experts give scores for the binary comparisons between the items. Super Decision directly does the evaluations for the matrices based on the scores given by the experts. According to these matrices and other datas, software determines the weight vectors of each and every item. While calculating the weight vectors, related checks must be done to have the right values. In the end these weight vectors will be used to priorities the risks. AHP and Super Decision have been used by many sectors and in many industries, under this study AHP and Super Decision will support the process for prioritizing the risks for Marmaray Project.

CHAPTER 7

RISK PRIORITIZATION

7.1 Combination Of The Findings and Risk Prioritization

For the beginning, five different risk factors were chosen. These are; technical risks, human factors, risks related with nature, construction risks and management risks. For every branch, there are subsets which are related with the risk classification. For example there are risk factors related with technical issues as nodes under the technical risk section. For each and every sub branch, experts gave score for possibility of occurrences and severity of the accidents for the related risk item. The aim was to get the results suitable for 5 x 5 matrices. Experts gave scores from one to five for every item.

As a basic risk mitigation strategy, experts give scores from one to five, from low to high degrees. After three interviews, risk scores for every sub branch has been given by the experts. To finalize the scoring phase, mean values of the risk scores calculated and a summary risk table was created. During the scoring, experts assumed that this risk scoring process is ongoing for the Marmaray Project. So according to this information, risk scores have been acquired. Marmaray Project is a very special project, even for tunnel construction community and for the region.

After risk scoring, experts ideas again needed for the AHP simulation. Super decision is a free program and it help to calculate AHP steps automatically. For the beginning, Super Decision program can be downloaded on the web site https://superdecisions.com freely.

After installing the program, every main branch and nodes have been constituted as clusters. As it was mentioned before, five main clusters was formed;

A.Technical Risks

B.Risks Related With Nature

C.Human Factors Risks

D.Construction Risk Factors

E.Management Risks

As the next step, for the binary comparisons between these main branches/clusters, experts gave scores from one to nine for each comparison according to priority of the elements during the binary comparisons. In the end, every cluster had rating with other clusters, and super decision program creates the matrices according to the experts' scores. On the Figure 7.1 main clusters are shown. Arrows are basically

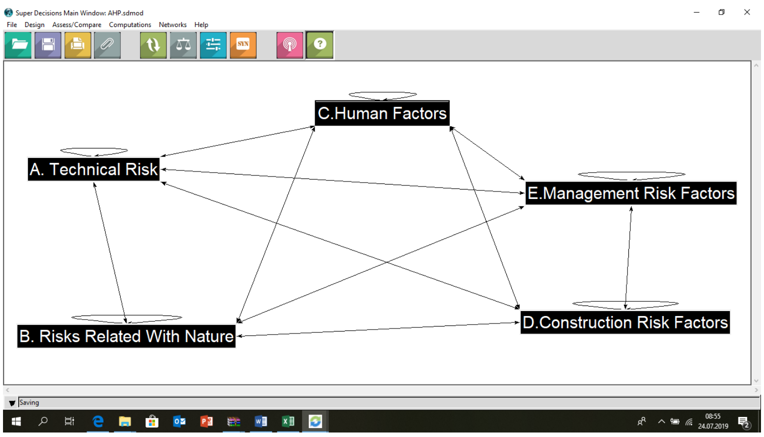


Figure 7.1: Main Clusters In Super Decision

symbolizing the relations between elements. There are also some arrows at the top of every element, circling. Which means that element was compared inside with itself.

For the comparisons of the main clusters, software supplies a scoring table just like in the figure. Values have been choosen by the experts, for each comparison, if two items have an equal effect or priority, one should be chosen as the score from the scale. From one to nine, risk prioritization gets higher degrees. It can be chosen from the blue or the red scale according to the elements. If the blue side has the priority, experts pick the rates from the blue side, if the red side is more important than they use from the red side. For every raw, there is only two alternatives. With this dual comparisons, each and every element gets scored with the rest of the clusters.

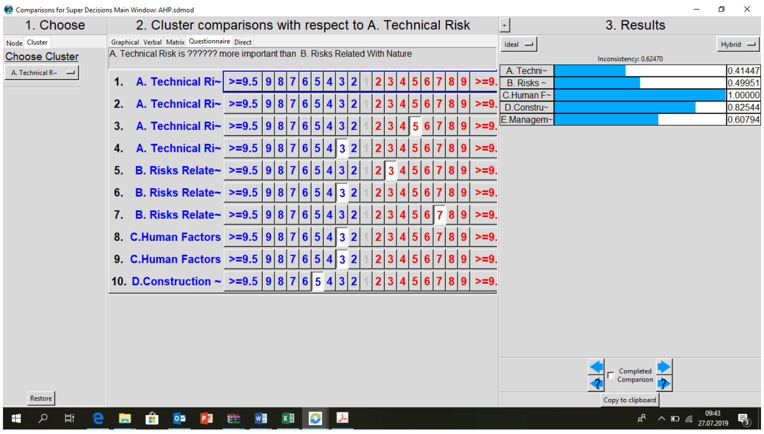


Figure 7.2: Binary Comparison In Super Decision

In the end of this step, a prioritization was observed between the 5 main risk groups. After giving the scores for the binary comparisons, Super Decision software calculates the matrices.

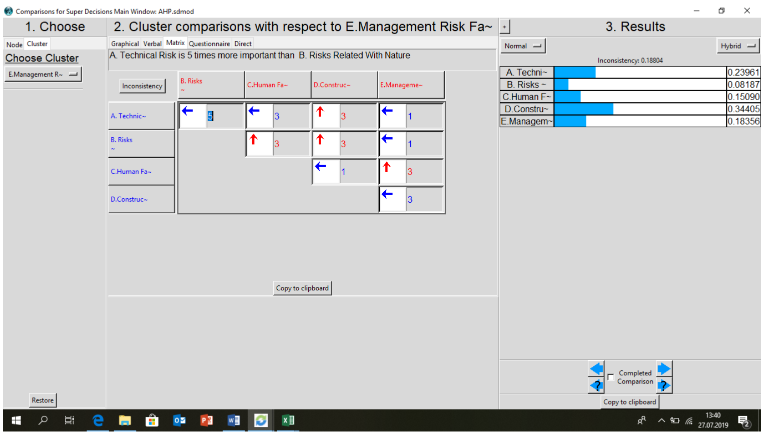


Figure 7.3: Weight Matrix In Super Decision

Within this matrices, weight vectors also calculated by the software.

Matrices for the main cluster is shown above, this matrices directly taken from the Super Decision outputs. On the other hand, software also gives the weight vectors for every item. So the decision maker should priorities the risks.

	A. Technical Risk	B. Risks Related With Nature	C.Human Factors	D.Construction Risk Factors	E.Management Risk Factors
A. Technical Risk	1	5	3	0,33	1
B. Risks Related With Nature	0,2	1	0,33	0,33	1
C.Human Factors	0,33	3	1	1	0
D.Construction Risk Factors	3	3	1	1	3
E.Management Risk Factors	1	1	3	0,33	1

Table 7.1: Matrix Between Main Clusters

Under the column "Normalized", there are weight vectors for each item. Total sum of these 5 numbers is equal to one. According to experts perception and comments, D.Construction risk factors has the highest rate above other four risk groups. When we consider experts' scores for the Marmaray Project, this item has high rates too. Mainly, construction risk factors has very high ratio when it is compared with other elements. Technical risk is the second important risk factor on the list. From third to fifth risks on the list are management risk factors, human factors and risks related with nature. When the importance of the construction risk factors and risks related with nature dually compared, importance of construction risk factors have an dominance more than four times than priority of risks related with nature. All these weights for the priorities will join the calculations at the last steps of the calculations, after the subbranches weight vectors derived. Every sub branch will be multiplied with the it's main group weight vector.

After this step, calculations for the sub branches will be operated by the software. Every node identified manually under the clusters, after that each and every item under every cluster are compared. The comparison stage is the same with the cluster prioritization phase. Experts give scores for the binary comparisons and finally software supplies the weight vectors.

Just like the clusters, matrices for the sub branches also determined by the software.

Every element has binary comparisons with each other. The below sample belongs to A. Technical Risk Factors. It is shown that 14th raw and 14th column the value in the cell of the intersection is 1, which means A14. Lack of Maintenance Failure has

	A1.TBM Related Risks	A2.TBM Installing Risk	A3.TBM Dismantling	A4.TBM Accidents Risks	A5.TBM Plants Risks	A6.NATM Related Risks	A7.Drilling Accidents	A8.Excavation Accidents	A9.Blasting Accidents	A10.Temporary Support Risks	A11.Cave-In Collapses	A12.Deformation of The Tunnel Tube and The Overburden	A13.Ventilation Risks	A14.Lack of Maintanance Failure
A1.TBM Related Risks	1.0	5	3	0.20000000000000001	5	0.20000000000000001	3	0.20000000000000001	5	7	3	5	0.20000000000000001	0.20000000000000001
A2.TBM Installing Risk	0.20000000000000001	1.0	5	5	0.33333333333333331	5	5	0.14285714285714285	5	5	0.20000000000000001	5	5	0.20000000000000001
A3.TBM Dismantling	0.33333333333333331	0.20000000000000001	1.0	0.20000000000000001	5	0.33333333333333331	3	0.33333333333333331	5	0.33333333333333331	3	3	5	3
A4.TBM Accidents Risks	5.0	0.20000000000000001	5.0	1.0	5	3	5	0.33333333333333331	1.0	5	0.20000000000000001	3	5	7
A5.TBM Plants Risks	0.20000000000000001	3.0	0.20000000000000001	0.20000000000000001	1.0	3	3	5	0.20000000000000001	1.0	0.14285714285714285	0.1111111111111111	5	3
A6.NATM Related Risks	5.0	0.20000000000000001	3.0	0.33333333333333331	0.33333333333333331	1.0	3	5	5	7	0.20000000000000001	0.14285714285714285	3	3
A7.Drilling Accidents	0.33333333333333331	0.20000000000000001	0.33333333333333331	0.20000000000000001	0.33333333333333331	0.33333333333333331	1.0	0.33333333333333331	0.14285714285714285	3	0.14285714285714285	3	0.14285714285714285	0.20000000000000001
A8.Excavation Accidents	5.0	7.0	3.0	3.0	0.20000000	0.20000000	3.0	1.0	5	0.20000000000000001	0.14285714	3	0.33333333	3
A9.Blasting Accidents	0.20000000000000001	0.20000000000000001	0.20000000000000001	1.0	5.0	0.20000000000000001	7.0	0.20000000000000001	1.0	7	0.14285714285714285	5	1.0	5
A10.Temporary Support Risks	0.14285714285714285	0.20000000000000001	3.0	0.20000000000000001	1.0	0.14285714285714285	0.33333333333333331	5.0	0.14285714285714285	1.0	0.33333333333333331	3	0.33333333333333331	0.20000000000000001
A11.Cave-In Collapses	0.33333333333333331	5.0	0.33333333333333331	5.0	7.0	5.0	7.0	7.0	7.0	3.0	1.0	5	3	7
A12.Deformation of The Tunnel Tube and The Overburden	0.20000000000000001	0.20000000000000001	0.33333333333333331	0.33333333333333331	9.0	7.0	0.33333333333333331	0.33333333333333331	0.20000000000000001	0.33333333333333331	0.20000000000000001	1.0	1.0	3
A13.Ventilation Risks	5.0	0.20000000000000001	0.20000000000000001	0.20000000000000001	0.20000000000000001	0.33333333333333331	7.0	3.0	1.0	3.0	0.33333333333333331	1.0	1.0	3
A14.Lack of Maintanance Failure	5.0	5.0	0.33333333333333331	0.14285714285714285	0.33333333333333331	0.33333333333333331	5.0	0.33333333333333331	0.20000000000000001	5.0	0.14285714285714285	0.33333333333333331	0.33333333333333331	1.0

Table 7.2: Weight Matrix For Cluster “A”

equal priority when its considered with itself.

Weight vectors of the A. Technical risk factors are also given below;

For every risk group, weight vectors determined by the Super Decision. With experts comments and interviews, binary comparisons are done by the software.

Inconsistency	0,65609			
Name	Normalized	Idealized		Total Weight
A1.TBM Related Risks	**0,090108007**	0,610896189	A1.TBM Related Risks	0,021591157
A2.TBM Installing Risk	**0,092411644**	0,626513925	A2.TBM Installing Risk	0,022143141
A3.TBM Dismantling	**0,068420957**	0,463866681	A3.TBM Dismantling	0,016394632
A4.TBM Accidents Risks	**0,096776534**	0,656106131	A4.TBM Accidents Risks	0,023189031
A5.TBM Plants Risks	**0,059350635**	0,402373528	A5.TBM Plants Risks	0,014221254
A6.NATM Related Risks	**0,080898445**	0,548459049	A6.NATM Related Risks	0,019384416
A7.Drilling Accidents	**0,018973482**	0,128632609	A7.Drilling Accidents	0,004546316
A8.Excavation Accidents	**0,088502391**	0,600010756	A8.Excavation Accidents	0,021206429
A9.Blasting Accidents	**0,056903885**	0,385785543	A9.Blasting Accidents	0,013634978
A10.Temporary Support Risks	**0,039044253**	0,264704394	A10.Temporary Support Risks	0,009355557
A11.Cave-In Collapses	**0,147501341**	1	A11.Cave-In Collapses	0,035343415
A12.Deformation of The Tunnel Tube and The Overburden	**0,056506279**	0,383089938	A12.Deformation of The Tunnel Tube and The Overburden	0,013539706
A13.Ventilation Risks	**0,052150343**	0,353558435	A13.Ventilation Risks	0,012495962
A14.Lack of Maintanance Failure	**0,052451804**	0,355602217	A14.Lack of Maintanance Failure	0,012568197

Table 7.3: Weight Vectors For The Risks Under Cluster "A"

The yellow column on the weight vectors table for the A. Technical Risk Factors has the related ratios to see their importance of risks and prioritize all project risks together under the cluster A.

	B1.Earthquake Risk	B2.Land Slide Risk	B3.Poison Gas Risk	B4.Radon	B5.Asbestos	B6.Carbon Monoxide	B7.Risks Related With Ground Water	B8.Tunnel Flooding
B1.Earthquake Risk	1.0	3	0.3333	0.3333	3	0.2000	3	3
B2.Land Slide Risk	0.3333	1.0	0.2000	0.2000	0.3333	0.14285	5	3
B3.Poison Gas Risk	3.0	5.0	1.0	5	1.0	1.0	0.3333	5
B4.Radon	3.0	5.0	0.2000	1.0	1.0	0.3333	5	3
B5.Asbestos	0.3333	3.0	1.0	1.0	1.0	0.3333	5	3
B6.Carbon Monoxide	5.0	7.0	1.0	3.0	3.0	1.0	5	5
B7.Risks Related With Ground Water	0.3333	0.2000	3.0	0.2000	0.2000	0.2000	1.0	3
B8.Tunnel Flooding	0.3333	0.3333	0.2000	0.3333	0.3333	0.2000	0.3333	1.0

Table 7.4: Weight Matrix For The Risks Under Cluster "B"

	C1.Cut/ Buruise of The Workers	C2.Falling From High	C3.Unproper Usage of Equipments	C4.Unproper Lifting/Transporting Operations	C5.Training Failure	C6.Supervising Failure	C7.Lack of Inspection Failure	C8.Accidents Related With Unproper Lighting	C9.Accidents Related With Communication
C1.Cut/ Buruise of The Workers	1	0,2	3	0,333333333	0,2	0,333333333	1	3	0,333333333
C2.Falling From High	5	1	5	3	7	5	3	9	3
C3.Unproper Usage of Equipments	0,333333333	0,2	1	0,333333333	3	1	5	5	3
C4.Unproper Lifting/Transporting Operations	3	0,333333333	3	1	3	1	3	0,333333333	0,333333333
C5.Training Failure	5	0,142857143	0,333333333	0,333333333	1	1	5	3	3
C6.Supervising Failure	3	0,2	1	1	1	1	5	7	5
C7.Lack of Inspection Failure	1	0,333333333	0,2	0,333333333	0,2	0,2	1	0,333333333	0,333333333
C8.Accidents Related With Unproper Lighting	0,333333333	0,111111111	0,2	3	0,333333333	0,142857143	3	1	3
C9.Accidents Related With Communication	3	0,333333333	0,333333333	3	0,333333333	0,2	3	0,333333333	1

Table 7.5: Weight Matrix For The Risks Under Cluster “C”

	D1.Collapse of Crane	D2.Materials Falling From Height	D3.Damaging Existing Utilities	D4.Damaging Existing Buildings	D5.Electricity Risks	D6.Fire Risks	D7.Dust Explosions Accidents	D8.Risks Related With Jacking Force	D9.Noise	D10.Rock Burst	D11.Mud Rush
D1.Collapse of Crane	1	7	7	7	3	3	9	3	9	3	3
D2.Materials Falling From Height	0,142857143	1	3	1	3	1	3	3	5	0,2	1
D3.Damaging Existing Utilities	0,142857143	0,333333333	1	1	1	0,333333333	3	1	5	0,2	3
D4.Damaging Existing Buildings	0,142857143	1	1	1	3	0,333333333	5	3	7	0,333333333	3
D5.Electricity Risks	0,333333333	0,333333333	1	0,333333333	1	0,333333333	5	3	5	3	5
D6.Fire Risks	0,333333333	1	3	3	3	1	0,333333333	5	7	0,333333333	3
D7.Dust Explosions Accidents	0,111111111	0,333333333	0,333333333	0,2	0,2	3	1	1	3	0,333333333	0,333333333
D8.Risks Related With Jacking Force	0,333333333	0,333333333	1	0,333333333	0,333333333	0,2	1	1	5	0,333333333	1
D9.Noise	0,111111111	0,2	0,2	0,142857143	0,2	0,142857143	0,333333333	0,2	1	0,2	3
D10.Rock Burst	0,333333333	5	5	3	0,333333333	3	3	3	5	1	5
D11.Mud Rush	0,333333333	1	0,333333333	0,333333333	0,2	0,333333333	3	1	0,333333333	0,2	1

Table 7.6: Weight Matrix For The Risks Under Cluster “D”

	E1.Key Date Risks	E2.TBM Stuck In Accidents	E3.Terrorism/Safety of the Site	E4.Accidents Related With Wrong Design	E5.Accidents Related With Wrong Working Shifts
E1.Key Date Risks	1	0,142857143	3	0,333333333	1
E2.TBM Stuck In Accidents	7	1	7	5	7
E3.Terrorism/Safety of the Site	0,333333333	0,142857143	1	3	3
E4.Accidents Related With Wrong Design	3	0,2	0,333333333	1	3
E5.Accidents Related With Wrong Working Shifts	1	0,142857143	0,333333333	0,333333333	1

Table 7.7: Weight Matrix For The Risks Under Cluster "E"

Just like matrices, each sub branch weight vector was calculated too.

Inconsistency	0,28975			
Name	Normalized	Idealized		Total Weight
B1.Earthquake Risk	0,107165762	0,414522604	B1.Earthquake Risk	0,008774036
B2.Land Slide Risk	0,068683436	0,265671015	B2.Land Slide Risk	0,005623354
B3.Poison Gas Risk	0,1948284	0,753606134	B3.Poison Gas Risk	0,015951284
B4.Radon	0,142732161	0,552095239	B4.Radon	0,011685982
B5.Asbestos	0,118074345	0,456717557	B5.Asbestos	0,00966716
B6.Carbon Monoxide	0,25852815	1	B6.Carbon Monoxide	0,021166605
B7.Risks Related With Ground Water	0,08316291	0,321678356	B7.Risks Related With Ground Water	0,006808839
B8.Tunnel Flooding	0,026824835	0,103759821	B8.Tunnel Flooding	0,002196243

Table 7.8: Weight Vectors For The Risks Under Cluster "B"

Inconsistency	0.28640			
Name	Normalized	Idealized		Total Weight
C1.Cut/ Buruise of The Workers	**0,066172424**	0,213729128	C1.Cut/ Buruise of The Workers	0,009985511
C2.Falling From High	**0,309608823**	1	C2.Falling From High	0,046720405
C3.Unproper Usage of Equipments	**0,1108894**	0,358159688	C3.Unproper Usage of Equipments	0,016733366
C4.Unproper Lifting/Transporting Operations	**0,106616046**	0,344357261	C4.Unproper Lifting/Transporting Operations	0,016088511
C5.Training Failure	**0,101242604**	0,327001674	C5.Training Failure	0,015277651
C6.Supervising Failure	**0,137242869**	0,443278287	C6.Supervising Failure	0,020710141
C7.Lack of Inspection Failure	**0,028386828**	0,091686109	C7.Lack of Inspection Failure	0,004283612
C8.Accidents Related With Unproper Lighting	**0,066785723**	0,215710011	C8.Accidents Related With Unproper Lighting	0,010078059
C9.Accidents Related With Communication	**0,073055283**	0,235959953	C9.Accidents Related With Communication	0,011024144

Table 7.9: Weight Vectors For The Risks Under Cluster "C"

Inconsistency	0.20540			
Name	Normalized	Idealized		Total Weight
D1.Collapse of Crane	**0,268333596**	1	D1.Collapse of Crane	0,092320475
D2.Materials Falling From Height	**0,085968248**	0,32037825	D2.Materials Falling From Height	0,029577472
D3.Damaging Existing Utilities	**0,054657244**	0,203691393	D3.Damaging Existing Utilities	0,018804886
D4.Damaging Existing Buildings	**0,089306991**	0,332820759	D4.Damaging Existing Buildings	0,03072617
D5.Electricity Risks	**0,101041331**	0,376551175	D5.Electricity Risks	0,034763383
D6.Fire Risks	**0,108610761**	0,404760205	D6.Fire Risks	0,037367654
D7.Dust Explosions Accidents	**0,046040136**	0,171577979	D7.Dust Explosions Accidents	0,01584016
D8.Risks Related With Jacking Force	**0,037810078**	0,140906985	D8.Risks Related With Jacking Force	0,0130086
D9.Noise	**0,020769133**	0,077400421	D9.Noise	0,007145644
D10.Rock Burst	**0,14986093**	0,55848739	D10.Rock Burst	0,051559821
D11.Mud Rush	**0,037601551**	0,140129868	D11.Mud Rush	0,012936856

Table 7.10: Weight Vectors For The Risks Under Cluster "D"

Every yellow column shows the weight vectors of sub branches under clusters and every yellow column has a sum equal to one.

Inconsistency	0,23707			
Name	Normalized	Idealized		Total Weight
E1.Key Date Risks	0,116189291	0,208139133	E1.Key Date Risks	0,021327681
E2.TBM Stuck In Accidents	0,558228958	1	E2.TBM Stuck In Accidents	0,102468387
E3.Terrorism/Safety of the Site	0,135848802	0,243356781	E3.Terrorism/Safety of the Site	0,024936377
E4.Accidents Related With Wrong Design	0,133302735	0,238795807	E4.Accidents Related With Wrong Design	0,024469021
E5.Accidents Related With Wrong Working Shifts	0,056430213	0,101087936	E5.Accidents Related With Wrong Working Shifts	0,010358318

Table 7.11: Weight Vectors For The Risks Under Cluster "E"

After deriving weight vectors, these weight vectors will be multiplied with the cluster risk class weight vectors below so all the risks could be compared together and get prioritized;

Inconsistency	0,18804	
Name	Normalized	Idealized
A. Technical Risk	**0,239614192**	0,696449385
B. Risks Related With Nature	**0,081873503**	0,237969006
C.Human Factors	**0,150901399**	0,438601678
D.Construction Risk Factors	**0,344051121**	1
E.Management Risk Factors	**0,183559784**	0,533524737

Table 7.12: Weight Vectors For Main Clusters

The risk scores for the Marmaray Project has already been given by the experts. As a final step existing risk scores and cluster and sub branch weight vectors will be multiplied together.

With a specific color scale, it is easier to see the clusters. These weight vectors will be multiplied with the risk scores given by the experts and final risk prioritization risk table will be procured.

		Total Weight
TECHNICAL RISKS	A1.TBM Related Risks	0.021591157
	A2.TBM Installing Risk	0.022143141
	A3.TBM Dismantling	0.016394632
	A4.TBM Accidents Risks	0.023189031
	A5.TBM Plants Risks	0.014221254
	A6.NATM Related Risks	0.019384416
	A7.Drilling Accidents	0.004546316
	A8.Excavation Accidents	0.021206429
	A9.Blasting Accidents	0.013634978
	A10.Temporary Support Risks	0.009355557
	A11.Cave-In Collapses	0.035343415
	A12.Deformation of The Tunnel Tube and The Overburden	0.013539706
	A13.Ventilation Risks	0.012495962
	A14.Lack of Maintanance Failure	0.012568197
RISKS RELATED WITH NATURE	B1.Earthquake Risk	0.008774036
	B2.Land Slide Risk	0.005623354
	B3.Poison Gas Risk	0.015951284
	B4.Radon	0.011685982
	B5.Asbestos	0.00966716
	B6.Carbon Monoxide	0.021166605
	B7.Risks Related With Ground Water	0.006808839
	B8.Tunnel Flooding	0.002196243
HUMAN FACTORS RISKS	C1.Cut/ Buruise of The Workers	0.009985511
	C2.Falling From High	0.046720405
	C3.Unproper Usage of Equipments	0.016733366
	C4.Unproper Lifting/Transporting Operations	0.016088511
	C5.Training Failure	0.015277651
	C6.Supervising Failure	0.020710141
	C7.Lack of Inspection Failure	0.004283612
	C8.Accidents Related With Unproper Lighting	0.010078059
	C9.Accidents Related With Communication	0.011024144
CONSTRUCTION RISK FACTORS	D1.Collapse of Crane	0.092320475
	D2.Materials Falling From Height	0.029577472
	D3.Damaging Existing Utilities	0.018804886
	D4.Damaging Existing Buildings	0.03072617
	D5.Electricity Risks	0.034763383
	D6.Fire Risks	0.037367654
	D7.Dust Explosions Accidents	0.01584016
	D8.Risks Related With Jacking Force	0.0130086
	D9.Noise	0.007145644
	D10.Rock Burst	0.051559821
	D11.Mud Rush	0.012936856
MANAGEMENT RISKS	E1.Key Date Risks	0.021327681
	E2.TBM Stuck In Accidents	0.102468387
	E3.Terrorism/Safety of the Site	0.024936377
	E4.Accidents Related With Wrong Design	0.024469021
	E5.Accidents Related With Wrong Working Shifts	0.010358318
	TOTAL	1

Table 7.13: Risk Weight Vectors and Classifications

PROJECT RISK

Technical Risks

	Mean Possibility	Mean Severity	Mean Risk Score
TBM Related Risks	2,67	4,00	10,67
TBM Installing Risk	2,00	4,00	8,00
TBM Dismantling	2,67	4,00	10,67
TBM Accidents Risks	2,33	4,67	10,89
TBM Plants Risks	1,33	3,67	4,89
NATM Related Risks	2,00	3,67	7,33
Drilling Accidents	2,33	2,67	6,22
Excavation Accidents	2,33	3,33	7,78
Blasting Accidents	2,00	5,00	10,00
Temporary Support Risks	2,00	3,00	6,00
Cave-In Collapses	1,33	4,67	6,22
Deformation of The Tunnel Tube and The Overburden	1,67	3,00	5,00
Ventilation Risks	1,00	3,67	3,67
Lack of Maintanance Failure	1,33	3,33	4,44

Risks Related With Nature

	Mean Possibility	Mean Severity	Mean Risk Score
Earthquake Risk	1,33	5,00	6,67
Land Slide Risk	1,67	4,33	7,22
Poison Gas Risk	1,67	4,33	7,22
Radon	1,33	4,00	5,33
Asbestos	1,33	3,00	4,00
Carbon Monoxide	1,00	3,67	3,67
Risks Related With Ground Water	3,00	2,67	8,00
Tunnel Flooding	2,33	4,00	9,33

Human Factors

	Mean Possibility	Mean Severity	Mean Risk Score
Cut/ Buruise of The Workers	4,00	2,33	9,33
Falling From High	3,33	3,67	12,22
Unproper Usage of Equipments	3,33	3,00	10,00
Unproper Lifting/Transporting Operations	2,67	3,67	9,78
Training Failure	1,33	3,33	4,44
Supervising Failure	2,67	4,00	10,67
Lack of Inspection Failure	3,00	3,00	9,00
Accidents Related With Unproper Lighting	2,33	3,33	7,78
Accidents Related With Communication	2,67	2,67	7,11

Construction Rİsk Factors

	Mean Possibility	Mean Severity	Mean Risk Score
Collapse of Crane	1,67	4,67	7,78
Materials Falling From Height	3,00	4,00	12,00
Damaging Existing Utilities	3,33	3,67	12,22
Damaging Existing Buildings	2,33	3,33	7,78
Electricity Risks	3,00	4,00	12,00
Fire Risks	2,67	4,33	11,56
Dust Explosions Accidents	2,00	3,67	7,33
Risks Related With Jacking Force	2,33	2,67	6,22
Noise	2,67	3,00	8,00
Rock Burst	2,00	3,33	6,67
Mud Rush	1,00	3,33	3,33

Management Risk

	Mean Possibility	Mean Severity	Mean Risk Score
Key Date Risks	2,33	3,33	7,78
TBM Stuck In Accidents	1,67	5,00	8,33
Terrorism/Safety of the Site	2,00	4,33	8,67
Accidents Related With Wrong Design	2,00	4,33	8,67
Accidents Related With Wrong Working Shifts	3,00	3,67	11,00

Table 7.14: Risk Breakdown Structure For Marmaray Project

Mean values and final risk scores for the project risks related with Marmaray derived from the experts are shown in the table above. After determination of the risk scores for every item, each score will be summed up and calculated a risk score for Marmaray Project on the scale of hundred. That step also shows the risk level of project too. Total risk score of the project after the total addition of every risk is 372,89. By dividing this value to 1175, which equals to 100% for 47 elements on the list and which means all probability of occurrences and severities for each risk item scored as five and total 25 risk score is coming for every risk. Project risk scale on the scale of hundred point is 33,22% that means even the project risk score is close to major risk class, it is still in the moderate risk class. Moderate risk level tells that, project has some risks which may not have high probability of occurrences or high severity rates but still needed to be followed up and mitigate. While creating a risk assessment plan, decision makers should know that the project risks can give harm to working environment during the risk score of the project is not at the minor risk level. Especially determining the right methods just like engineering solutions, management solutions or using PPE to avoid those risks, risk prioritization is really important. With that overall scores, decision maker can also make some assumptions for the project and project sources generally about how to use them and how to stay without over reacting of these risks.

Minor	1-12
Moderate	13-36
Major	37-64
Severe	65-100

Figure 7.4: Risk Levels

Risk prioritization table found as a result of calculations is given in Table 7.15

	Risk Scores Given By Experts for MARMARAY	Risk Type	AHP Weights	Total Risk Score
TBM Related Risks	42,66666667	Major	0,021370669	0,911815226
TBM Installing Risk	32	Moderate	0,021917017	0,701344532
TBM Dismantling	42,66666667	Major	0,016227211	0,692361011
TBM Accidents Risks	43,55555556	Major	0,022952226	0,999696941
TBM Plants Risks	19,55555556	Moderate	0,014076028	0,27526454
NATM Related Risks	29,33333333	Moderate	0,019186463	0,562802908
Drilling Accidents	24,88888889	Moderate	0,004499889	0,111997234
Excavation Accidents	31,11111111	Moderate	0,02098987	0,653018173
Blasting Accidents	40	Major	0,013495739	0,539829545
Temporary Support Risks	24	Moderate	0,009260019	0,222240447
Cave-In Collapses	24,88888889	Moderate	0,034982489	0,870675288
Deformation of The Tunnel Tube and The Overburden	20	Moderate	0,01340144	0,268028793
Ventilation Risks	14,66666667	Moderate	0,012368354	0,181402528
Lack of Maintanance Failure	17,77777778	Moderate	0,012439851	0,221152902
Earthquake Risk	26,66666667	Major	0,013470325	0,359208661
Land Slide Risk	28,88888889	Moderate	0,008633244	0,249404832
Poison Gas Risk	28,88888889	Moderate	0,024489182	0,70746525
Radon	21,33333333	Minor	0,017940885	0,382738871
Asbestos	16	Moderate	0,014841492	0,237463869
Carbon Monoxide	14,66666667	Moderate	0,032495996	0,476607938
Risks Related With Ground Water	32	Major	0,010453258	0,334504271
Tunnel Flooding	37,33333333	Major	0,003371779	0,125879738
Cut/ Buruise of The Workers	37,33333333	Major	0,014862208	0,554855748
Falling From High	48,88888889	Major	0,069537586	3,399615301
Unproper Usage of Equipments	40	Moderate	0,02490556	0,9962224
Unproper Lifting/Transporting Operations	39,11111111	Major	0,023945773	0,936545771
Training Failure	17,77777778	Moderate	0,022738907	0,404247234
Supervising Failure	42,66666667	Moderate	0,030824502	1,315178747
Lack of Inspection Failure	36	Major	0,006375631	0,229522704
Accidents Related With Unproper Lighting	31,11111111	Moderate	0,014999953	0,466665216
Accidents Related With Communication	28,44444444	Moderate	0,016408085	0,466718875
Collapse of Crane	31,11111111	Major	0,072003862	2,240120144
Materials Falling From Height	48	Moderate	0,023068471	1,10728662
Damaging Existing Utilities	48,88888889	Moderate	0,014666567	0,717032159
Damaging Existing Buildings	31,11111111	Major	0,02396438	0,745558486
Electricity Risks	48	Moderate	0,027113139	1,301430659
Fire Risks	46,22222222	Major	0,029144298	1,347114213
Dust Explosions Accidents	29,33333333	Moderate	0,012354277	0,362392128
Risks Related With Jacking Force	24,88888889	Moderate	0,010145847	0,25251886
Noise	32	Moderate	0,005573129	0,178340135
Rock Burst	26,66666667	Moderate	0,040213249	1,072353303
Mud Rush	13,33333333	Moderate	0,010089892	0,134531889
Key Date Risks	31,11111111	Moderate	0,016754643	0,521255545
TBM Stuck In Accidents	33,33333333	Moderate	0,080497321	2,68324402
Terrorism/Safety of the Site	34,66666667	Major	0,019589569	0,679105053
Accidents Related With Wrong Design	34,66666667	Moderate	0,019222423	0,666377319
Accidents Related With Wrong Working Shifts	44	Moderate	0,008137308	0,358041553

Table 7.15: Risk Prioritization Table

All risk scores multiplied with four, to make the scale 100 rather than 25, because the first calculations referred 5 x 5 matrices.

There is a risk table and color scale below in the graphics.

According to all these informations, final risk prioritization table formed.

Minor					
Moderate					
Major					
Severe					
	20	40	60	80	100
	16	32	48	64	80
	12	24	36	48	60
	8	16	24	32	40
	4	8	12	16	20
5X5					

Figure 7.5: Risk Levels According To Risk Scores

	Risk Scores Given By Experts for MARMARAY	Risk Type	AHP Weights	Total Risk Score
Falling From High	48.889	Major	0.070	3.400
TBM Stuck In Accidents	33.333	Moderate	0.080	2.683
Collapse of Crane	31.111	Major	0.072	2.240
Fire Risks	46.222	Major	0.029	1.347
Supervising Failure	42.667	Moderate	0.031	1.315
Electricity Risks	48.000	Moderate	0.027	1.301
Materials Falling From Height	48.000	Moderate	0.023	1.107
Rock Burst	26.667	Moderate	0.040	1.072
TBM Accidents Risks	43.556	Major	0.023	1.000
Unproper Usage of Equipments	40.000	Moderate	0.025	0.996
Unproper Lifting/Transporting Operations	39.111	Major	0.024	0.937
TBM Related Risks	42.667	Major	0.021	0.912
Cave-In Collapses	24.889	Moderate	0.035	0.871
Damaging Existing Buildings	31.111	Major	0.024	0.746
Damaging Existing Utilities	48.889	Moderate	0.015	0.717
Poison Gas Risk	28.889	Moderate	0.024	0.707
TBM Installing Risk	32.000	Moderate	0.022	0.701
TBM Dismantling	42.667	Major	0.016	0.692
Terrorism/Safety of the Site	34.667	Major	0.020	0.679
Accidents Related With Wrong Design	34.667	Moderate	0.019	0.666
Excavation Accidents	31.111	Moderate	0.021	0.653
NATM Related Risks	29.333	Moderate	0.019	0.563
Cut/ Buruise of The Workers	37.333	Major	0.015	0.555
Blasting Accidents	40.000	Major	0.013	0.540
Key Date Risks	31.111	Moderate	0.017	0.521
Carbon Monoxide	14.667	Moderate	0.032	0.477
Accidents Related With Communication	28.444	Moderate	0.016	0.467
Accidents Related With Unproper Lighting	31.111	Moderate	0.015	0.467
Training Failure	17.778	Moderate	0.023	0.404
Radon	21.333	Minor	0.018	0.383
Dust Explosions Accidents	29.333	Moderate	0.012	0.362
Earthquake Risk	26.667	Major	0.013	0.359
Accidents Related With Wrong Working Shifts	44.000	Moderate	0.008	0.358
Risks Related With Ground Water	32.000	Major	0.010	0.335
TBM Plants Risks	19.556	Moderate	0.014	0.275
Deformation of The Tunnel Tube and The Overburden	20.000	Moderate	0.013	0.268
Risks Related With Jacking Force	24.889	Moderate	0.010	0.253
Land Slide Risk	28.889	Moderate	0.009	0.249
Asbestos	16.000	Moderate	0.015	0.237
Lack of Inspection Failure	36.000	Major	0.006	0.230
Temporary Support Risks	24.000	Moderate	0.009	0.222
Lack of Maintanance Failure	17.778	Moderate	0.012	0.221
Ventilation Risks	14.667	Moderate	0.012	0.181
Noise	32.000	Moderate	0.006	0.178
Mud Rush	13.333	Moderate	0.010	0.135
Tunnel Flooding	37.333	Major	0.003	0.126
Drilling Accidents	24.889	Moderate	0.004	0.112

Table 7.16: Final Risk Prioritization Table

These results can be approached in many different ways and used as a pathfinder during the risk mitigation strategy set up phase. Total project risk score is 33,22 above 100 points. That means project has a moderate risk for construction activities. While this study was detailed risk score may be found a little bit low for a mega project. There are some major risks and some risks have priority because of their possible affects on project. Risk priority study becomes more meaningful after this result as well. Because making perceptions and avoiding risks are not clear every time, if a project management should follow only the total risk score and gives decisions according to main risk score of the project, some very important risks could be passed over. Without understanding the priorities of project and possible risk factors, risk mitigation strategies and risk counter measurements will be tentative. Even the main risk score is not very high for the project, there are major risks with high priority and operations must be planned regarding that information.

Risk Groups	Total Risk Scores From The Main Risk Groups	Percentages of Risk Groups
Technical Risks	7,212	22%
Risks Related With Nature	2,873	9%
Human Factors	8,770	26%
Construction Risk Factors	9,459	28%
Management Risk	4,908	15%
TOTAL	33,222	100%

Table 7.17: Final Risk Ratings For Marmaray Project

Above in the table, it is also shown with the total risk score of the project, risk ratings of individual clusters and percentages of them. Highest risk rating belongs to Construction Risk Factors group and 28% of the total risk score comes from this main group. Even that information can help to create a more trustworthy risk prevention strategy. Different risks have different risk scores from expert interviews and AHP outputs, risks with similar sources or risks have resemblances creates main risk groups/clusters and cluster risk score comes from these individual risks. Five main risk groups were identified and project risk score is the sum total of risk scores belong to five main risk groups. Finally total risk score is 33,22 above 100 points.

7.2 Comments on Risk Prioritization Rankings

According to the table and risk scores given by the experts before, for Marmaray Project there are minor, moderate and major risks were determined. No severe risk was rated for the Marmaray Project by the experts. Totally fifteen major risks were found and four of the top five risks on the list are major risks.

Falling from high is very common work accident in construction projects. Statistics show that construction industry has a much higher rate for the fatal work accidents when its compared with other industries. And most common root cause for the fatal accidents in construction projects is falling from high (Liy et al., 2016). Even it is not a superstructure project, experts gave the highest risk score to this item for the Marmaray Project too.

After the first and most important risk on the list, “Collapse of Crane” has the second priority. Marmaray Project had so many lifting operations under the scope. Even from the basic operations to transportation of immersed tunnel tubes and when it is necessary TBM parts could have hazardous lifting operations and cranes must be ready to work. According to literature surveys and data mentioned before, all checks and inceptions must been done before the operations. Maintenance is one of the most crucial element for the activities which requires human-machinery interactions. Periodic maintenance can prevent big accidents. Independent from size of the project, if crane is needed during the operations, operators needed to be educated and aware not only about the construction site, collapse of a crane can damage the environment near construction site too. During every lifting operations there is a risk for fatal accident, which makes experts comments understandable.

Third risk on the table is "TBM Stuck In Risk". It is a nightmare for every contractor to live this situation during a tunnel project. TBM is an expensive machine and it can have a cost more than 10 million Euro easily. Before in this study, TBM supply chain has been mentioned, how much time does it take to order, purchase and transport TBM to the construction site were highlighted. If any accidents happen with an item costly and needed months to purchase and transport just like TBM during any project phase, it is obvious project management will get a great damage out of it. And if the incident is not like a normal accident, if it is a stuck in situation, there is not much option to do. Contractor may try to save it and spend much time and money. Without adequate surveys and wrong type machinery choosing, it is not a unique accident type anymore. It can lead up to environmental damages too. Under these circumstances it is not surprising to have this item at the top of the list as long as it is a tunnel construction project.

Fourth important risk determined by the experts for Marmaray Project is "Fire Risk". For every confined space operations, fire means danger. In Marmaray project HES manual fire protection was mentioned detaily. Even for the construction elements, In July 2011, Effectis Nederland laboratory was tested for immersion and TBM tunnel sections. According to the Effectis-RWS procedures (2008 Effectis-R0695) these tests were carried out on a representative tunnel section. These tests excluded three points;

i) The swelling effect of concrete that may occur in anchors in immersed tunnels.
ii) The swelling effect of the concrete that may occur on the anchors in the TBM tunnel.
iii) The maximum temperature that may occur between the two CPC segments.

In this report, these three elements are explained by the finite element method and some thermal calculations.

In addition, some adaptations have been made due to air gaps that may occur in anchors and fire protection materials. The fire resistance of the concrete around the anchors was calculated by using the following fire curves;

-120 minutes RWS fire curve (max. 1350 Celcius)
-240n minutes Hydro Carbon Euro Code 1 fire curve (max. 1100 Celcius)

In terms of design, the worst scenarios stand out as concrete fragmentation in the area close to the anchors and the biggest problems occur near the bigger anchorage diameters. Anchors in other regions are both more discrete and smaller in diameter and therefore do not pose such a risk. All these M16 anchors were placed in the immersed tunnel structures before the concrete pouring phase.

The initial analysis were carried out with 33 mm Cafca spray mortar and 16 mm Radius anchorages. The curve of the sample subjected to the RWS fire test of 120 minutes is as shown in the figure.

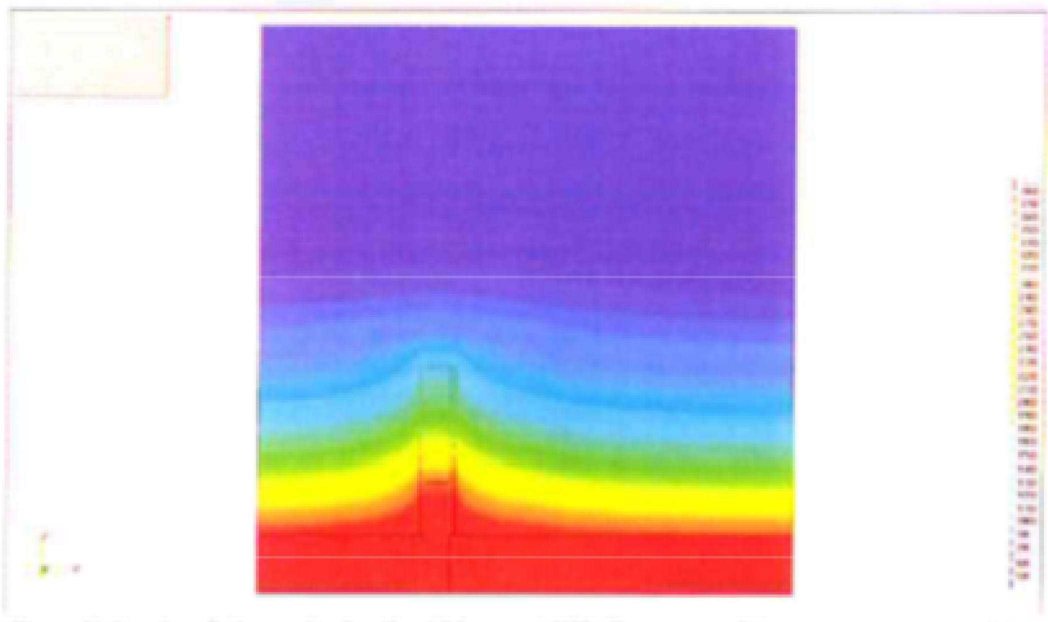


Figure 7.6: Fire Test Diagram for Anchorages

As shown in the Figure 7.6, the highest temperature values can be reached in the anchoring zone. Two kinds of alternative countermeasures have been taken against these temperature increases;

a)Spray mortar 33mm, anchoring radius 12mm

b) Spray mortar 48mm, anchoring radius 16mm

It is obvious Marmaray Project management saw the same risks related with fire, not only as a human factors risk, they also consider the fire as a technical risk and they aimed to make the week parts of the system stronger for the fire. Our experts saw the same risks, they were aware about the consequences and in the end fire risk had a high ranking in the list.

Not for every tunnel project, but if the project exists in a city like İstanbul, there is always risk to damage the buildings during the construction phase. For Marmaray project it was not only the buildings, it was also archaeological findings. Numerous times construction operations stopped because of the environmental issues. That is why experts gave high scores for this item.

CHAPTER 8

CONCLUSION

Throughout the study; health and safety risks for construction projects, specific tunnel construction risks, creating a safe working environment with effective risks measurement and assessment methods, how to avoid those risks and how to priorities them to create risk mitigation strategies were introduced in detail. According to experts' interviews and comments, risk scores for Marmaray Projects were given above in a rating scale from one to five. Later on, to make the risk prioritization, AHP was used as a method. AHP calculations was completed by using Super Decision software, ratings of each and every risk factor for AHP also was decided by the same experts. The main objective of this study is to focus on the risks in the tunnel construction and classify and priorities them according to their importance. Experts' comments and ratings was combined with AHP outputs and finally risk prioritization list for Marmaray was observed.

When this list is compared with literature survey findings and experts comments, it is pretty understandable and it makes the decision making process easier. Management level needs to make some choices during every construction project. Even before the projects and site execution steps, this kind of studies could help to choose the right ways to complete the construction. Risk prioritization does not mean to only focusing on the highest rated risks but that can help to give enough attention for each and every item. Losing time and finance with a risk which has no priority during this project could cause missing out the risks which could lead greater hazards. As each project has different characteristics, risk prioritization must be done specially.

On the list prioritization list, risks are classified according to the their severity levels too. Most of the risks have moderate effect on the Project. According to these list, top five items also have been mentioned. Rather than these top five risks, TBM related risks, TBM accident risks had high scores as well. Before the AHP calculations, these risks were more considerable but after AHP and binary comparison applications, it has been decided these risks have less priority for the Marmaray Project. TBM related risks are highly related with experience of the contractor, geological conditions, choosing the right type of machinery. Experts did not find these items too risky when they are compared with the top five risks just like TBM stuck in risk.

On the other hand, risks with less effect on the project just like minor risks found place at the bottom of the risk prioritization table. Which supports that the AHP comparisons and risk scoring done by experts have a relationship between each other. With the combination of these approaches some risks became more momentous and some got more insignificant. Which was the main objective of this study.

While there are various risk factors and limited project sources, risk mitigation strategies are highly dependent on the financial and technical capability of the project management. This study focuses on to use these project sources on the right way with correct gradation. Other than that, combining AHP and experts' scores give a chance to spend the limited sources in a feasible way. The risk mitigation strategy should be unique for every tunneling project . For example, if the project area covers archaeological findings than there is a risk for delay and this risk could have also a bigger effect on the project than the other factors. Binary comparisons and combination of risk scores will show the result.

On the other hand, Marmaray Project top risks on the risk prioritization list are mostly related with technical and human factors. Rather than these risk sources, as it is a well known issue, earthquake risk is threatening the region. In the past, earthquakes gave damages to Istanbul and the cities close to Istanbul too. Many people died, a lot of buildings collapsed and so many structures demolished afterwords the earthquake too. The not very far away history of the region has put the earthquake risk in a more dominant level during the binary comparisons, though the risk scores was not low too. But generally experts gave higher scores for risks related with human factors and technical issues. As it was mentioned before, many factors directly affect the human factors based risks. While it is a challenging activity to prevent from those risks by education and trainings, low personal awareness and other individual factors can easily trigger the accidents too. Technical risks are a bit different than other risk factors, data is needed to evaluate the risks, surveys must be done, management should be aware from the early design phase, all material searches and decision making processes should be done wisely. Just like Marmaray Project, borehole openings and research drillings should be performed. Decision making processes should be supported with data related with risk sources, than there will be a chance to prevent form those risks.

Even though datas are collected, they are not enough to create a risk mitigation strategy. For this purpose, decision makers should use these datas and experts' experiences to understand the effects of these risks on the project . While each and every risk has a consequence, project directors must compare these risks within each other and create a risk prioritization list. Which was performed during this study. Risk ratings and AHP were used together to create a risk ranking list especially for Marmaray Project. This method is valuable and can be used in other construction projects too, just like superstructure and water projects while they have their complex environments for decision making and understanding the risks too.

To sum up, creating risk mitigation strategies, making the right decisions and prioritizing the risks are saving, lives, time and money for tunnel construction projects. Combining the ratings given by experts with AHP helps determine the safest ways to finalize the projects. Tunnel construction is a complex work in a complex environment, even the most experienced managers and supervisors can make wrong decisions no matter how experienced and aware they are. Using AHP and experts ratings to create a risk prioritization list during every project can help to create a safe working environment, which makes this study precious.

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