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DEVELOPING GUIDELINE FOR RISK MANAGEMENT OF TUNNEL CONSTRUCTION IN ETHIOPIA

A Thesis in civil railway engineering

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A Thesis

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The undersigned have examined the thesis entitled '**DEVELOPING GUIDELINE FOR RISK MANAGEMENT OF TUNNEL CONSTRUCTION IN ETHIOPIA**' presented by **Nigussie h/mariam**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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DECLARITION

I certify that research work titled "DEVELOPING GUIDELINE FOR RISK MANAGEMENT OF TUNNEL CONSTRUCTION IN ETHIOPIA" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Nigussie H/mariam

Abstract

Tunnel construction involves complex projects that encompass various types of risk. These risks can influence the project in different situation. It is important to gain deep understanding of the risks associated with tunneling in order to reduce the likelihood of their occurrence and severity of their consequence should they occur. For this to be achieved, different risk should first be evaluated and ranked according their risk level.

To achieve project goals, it is necessary to adopt appropriate risk management strategies from project inception to project completion. Risks can be managed in different ways directly or indirectly using engineering decisions, but at this time improving systematic and well organized risk management techniques are important.

This paper studies about the current tunnel practices in Ethiopia, the main challenges and risks which were associated with tunneling, risk assessment and controlling measures. In doing so risk factors causing delay, increasing total cost, degrading quality, and decreasing the operation rate were also identified and ranked based on their impact and occurrence using risk matrix method. For this purpose questioner designed and completed by tunneling experts. By responding to the questioner the experts determined the likelihood and impact of the risks. As a result the tunneling experts suggested the alternative response method for controlling risks.

As result of performing the qualitative analysis it is concluded that risk matrix is an effective tool in identifying, ranking the risks involved in such project. It was also concluded that by taking into account different alternatives when analyzing and ranking risk its impact can be reduced and the projects efficiency also increased.

Guideline is then prepared in order to give guidance for all of these who have the job of preparing the overall scheme for the identification and management of risks in tunneling and underground projects in Ethiopia. The guideline can help for those futures planned tunneling projects in Ethiopia. This provides owners, contractors and consultants with what is modern-day industry practice for risk assessment, and describes the stages of risk management throughout the entire project implementation.

Keywords: tunnel, risk, risk analysis, risk management, control measures, guideline.

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Acronyms and abbreviations

AKH	Awash Kombolcha Haragebeya railway project
AALRT	Addis Ababa Light Rail Transit
ERC	Ethiopian Railway Corporation
FHWA	Federation of Highway Association
GTP	Growth and Transformation Plan
ITA	International Tunneling Association
NATM	New Australia Tunneling Method
NRNE	National Railway Network of Ethiopia
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PPE	Personal Protective Equipment
RAM	Risk Analysis and Management
RMS	Risk Management System
RMR	Rock Mass Rating
TBM	Tunnel Boring Machine

CHAPTER 1 INTRODUCTION

1.1 Background of the study

The Ethiopian government has been undertaking several transportation projects as part of a five year Growth and Transformation Plan (GTP), which aims to enhance the transportation network within the country by connecting to adjacent country and ports. It will provide efficient mobility and improve the export and import activities, boosting the economic development. National Railway network of Ethiopia (NRNE) has planned railway projects which has been implementing in two phases. It has also endowed with natural resource of river, so the government of Ethiopia has constructed many hydropower plants, and there are also new projects under construction. These railways and hydropower projects incorporate a different type of tunnel works.

Tunnel construction projects tend to be large, complex, and expensive infrastructure undertakings that encompass various types of risk throughout the project life cycle. An essential tool for planning and controlling tunneling projects is risk management. Tunnelling and underground construction works impose risks on all parties involved as well as on those not directly involved in the project. The very nature of tunnel projects implies that any tunnel owner will be facing considerable risks when developing such a project. Due to the inherent uncertainties, including ground and groundwater conditions, there might be significant cost overrun and delay risks as well as environmental risks. Also, as demonstrated by spectacular tunnel collapses and other disasters in the recent past, there is a potential for large scale accidents during tunnelling work. Furthermore, for tunnels in urban areas there is a risk of damage to a range of third party persons and property, which will be of particular concern where heritage designated buildings are involved.

Risks can be managed in different ways directly or indirectly using engineering decisions, but at this time improving systematic and well organized risk management techniques are important. The use of risk management from the early stages of a project, where major decisions such as choice of alignment and selection of construction methods can be influenced, is essential.

The majority of past research on tunneling risk management had focused on risk-identification and risk-analysis [15], [20] and [12]. Few research projects have studied risk-response in tunnel construction [8].

In this paper guideline for risk management of tunnel construction in Ethiopia is adopted. This guide is prepared based on the current tunnel practices and main challenges happened during the tunneling phase in Ethiopia.

1.2 Problem Statement

Today Ethiopia's economy is growing well and transportation is very critical issue because of increasing transport demand of the country. Tunneling has become a preferred method of construction for road and highway projects in countries with a lot of hilly slope geological conditions such as found in Ethiopia. However the construction works of a tunneling project are usually complicated, uncertain and costly, which consequently impose great risks to the parties involved.

Compared to other types of linear infrastructure, this additional uncertainty arises from the unpredictable geotechnical environment, where the tunnels are built. Due to this reason or other different reasons, risk occurs during tunneling, and causes loss both on material and life. The collapse of tunnels causes to delay the completion date, unsafe work condition, and in general jeopardizes the economy. The risk can also causes indirect impacts on humans, other living things and environment. Therefore this study attempts to develop a guideline in order to identify and manage these risks.

1.3 Research Objectives

The general objective of this thesis is developing a guideline for risk management of tunnel construction in Ethiopia in reference to different standards.

The specific objectives are:-

- Investigating the current tunneling practices in Ethiopia
- Identifying and ranking the common risks associated with tunnel constructed using risk matrix
- Analyzing and evaluating the risk levels associated with tunneling works by qualitative analysis method
- Providing practical suggestion and recommendation to reduce risks and improve the projects goal.
- Developing risk control and monitoring guidance with reference of different standards

1.4 Scope of the study

The scope of the research is investigating on; the tunneling construction failures, tunneling risk management, and current tunnel practices in Ethiopia. The study carried out the qualitative risk analysis for the risks occurring during tunneling and based on the analysis risks are identified, ranked and control measures are developed. These controlling measures are studied for all tunneling phases and this can be used as guideline on future tunneling work.

1.5 limitation of the study

As the construction of tunnel is new technology to our country, there isn't well organized information, so gathering the required data for the study was difficult, and it was the limitation to get the required data in quantity and quality.

The risk analysis focused on negative effect only, the positive impact is not considered, and also during ranking the risk level, the probability and impact remains the same for all objectives (cost, time, quality, and scope) of the project.

1.6 Research methodology

The work of the study has two main parts as shown the figure below;

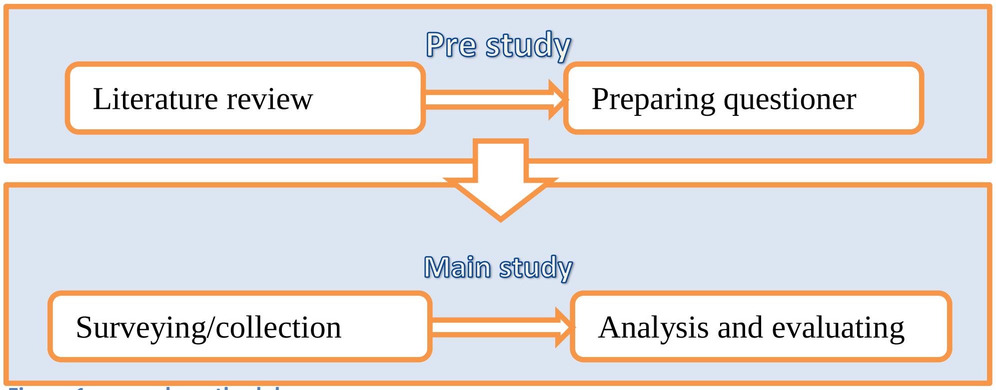

Figure 1 research methodology

- **Literature review**

This includes reviewing of current tunnel design and construction reports and publications. Detailed evaluation of the challenges encountered during the design and construction of tunnels. This includes evaluation of existing books, reports and journals.

- **Questioner survey**

To perform the study questioner was designed based on the literature review result (see Apex 1) and then the questioner papers were distributed to the tunneling project experts which involved in the design as well as in the construction work.

- **Data collection**

The relevant data was collected from the tunneling experts. Totally 20 questioner surveys were distributed and 15 of them are responded which means 75% of the surveying answer was replied. The analysis is then carried out based on this gained information.

- **Data analysis and evaluation**

The analysis is done based on the respondent data, and then qualitative risk analysis method is used to analyze the data collected. The identified risks are ranked and evaluated based on their risk level and different alternative response methods also described by the experts to reduce the risks impact on the project goal.

Finally by using different code of standards control measures for tunneling construction is developed.

1.7 Structure of the thesis

This thesis presents its work in six chapters;

- Chapter one establishes the introduction part, back ground of the study, problem statement, objectives and scope, methodology, limitation of the study and thesis out line.
- Chapter two covers the literature review part; that is by reviewing related research papers, standards which are important to this study.
- Chapter three of the thesis focuses on the investigating of current tunnel practices in Ethiopia, the challenges faces during the construction and the remedial measures taken.
- Chapter four presents the analysis part of the study.
- Chapter five aims at developing control measures for the risks associated with the different tunneling phase with reference to different standards.
- Chapter six concludes the research result and recommendations based on the findings either for further research or for considerations for making the results more acceptable and understandable.

CHAPTER 2 LITERATURE REVIEW

2.0 Introduction

The complexity of the tunnel design and construction process is incomparable to other infrastructure. Due to its complexity many risks can happen which influence the whole project or the party which are involved during the construction. It is difficult but necessary to fully comprehend how tunnels are procured and constructed in order to understand how risks will be managed. In this chapter, the background information regarding the tunnelling construction method, tunnel failures, ground uncertainties, design methods, supporting types and risk management for tunnel construction are discussed. More especially this chapter explains the risk management for tunnel construction and the steps how to manage if risks happen during construction and at service time of the project. Different risk factors are also discussed based on the past research papers. This chapter is a detail literature review about tunnel risk management of tunnel construction and reviewing books, thesis, standards and relevant website are carried out to develop this chapter.

2.1 Tunnel design and construction methods

Tunnel can be defined as underground passage constructed for the purpose of transportation connection between two points.

Tunnel design is different to plant or structure design because it is difficult to accurately pre-determine geological conditions, properties and variability along the tunnel. Therefore tunnel design is based on less reliable assumptions than other designs, due to that many risks can happen. Safe tunnel design and construction depends on pre-construction investigation of the ground conditions, the workplace and proper interpretation of this information [6].

To minimize the associated risk designers should be:

- provided with available and relevant information
- told of gaps in the information for planning and construction
- involved in collecting data during workplace investigations, and
- involved in site investigations

Tunnelling construction includes vertical and inclined shafts providing access to tunnels, portals where tunnels emerge at the surface or at a shaft, underground chambers and caverns. Construction work carried out in or near a tunnel or associated excavation is high risk construction work. Tunnelling work includes constructing a tunnel and supporting systems and associated temporary work. A supporting system means a system necessary to construct the tunnel, for example primary support like concrete lining, and secondary support for the tunnel construction, a ventilation system [30].

In the design and construction of a tunnel, different classification methods are commonly combined and a project specific classification system is defined. Applying the correct design method and classification system is very important in order to reduce the risks which can occur during construction and operation of the tunnel.

2.2 Tunnel construction failures and risks

Tunnel failures can be defined as unanticipated disastrous consequence of an event which adversely affects the physical safety of the underground structure. Physical collapse is indeed failure, as also is explosive and inrush of water.

Failures can broadly be divided in to two groups: those which occur during construction and those which happen after the tunnel is put in to service.

The failures during tunnel construction are the more frequent. To the credit of the engineer and designer, once a tunnel structure has been constructed it usually retains permanently its intended configuration. Credit for the successful creation of such a structure should go more to the construction engineer than to the designer. The important accomplishment must go to the excavation and support the cavity until the permanent lining has been installed [13].

The main Causes for failure are:

- uncertainty of the ground
- earthquake
- explosive mixture of air and gas
- pumping action of water
- method of excavation
- type of equipment and experience of working
- complexity and maturity of the applied technology
- technical and/or managerial incompetence
- human factors and/or human errors
- lack of sufficient communication and co-ordination between internal and external interfaces
- combinations of several unwanted events that individually are not necessarily critical

Tunnel construction failures are extraordinary events, which have severe impact on the construction process. They may cause high financial losses, severe delays or even human injuries or death. The control of tunnel failures risks is thus of crucial importance.

The most frequently reported tunnel construction failures are the cave-in collapses, tunnel flooding, portal instability or excessive deformation of the tunnel tube and the overburden. The tunnel construction failures can cause damages on adjacent buildings and infrastructure and they are thus especially adverse in tunnels built in the cities [36].

Efforts to learn a lesson from past errors led to the development of numerous databases of tunnel construction failures.

Tunnel failure causes;

- high financial losses
- unsafe working condition
- damage to working machineries
- death , injuries or Health problem to workers
- infrastructure losses
- delay the construction time
- damage to the adjacent buildings
- jeopardizes the economy of the country

2.2.1 Geotechnical uncertainty during tunnel construction

In tunneling there are a number of uncertainties in the ground support design and ground support implementation process. According to bachear and Christian uncertainties are grouped into two: uncertainty due to naturally variable phenomena in time or space and uncertainty due to lack of knowledge or understanding.

Mcmahon (1985) also listed six types of geotechnical uncertainties:

- risks of encountering unknown geological conditions
- risks of using incorrect geotechnical criteria
- bias or variation in estimated design parameters
- human errors
- design changes and excessive conservative

All these uncertainties occur in the design phase of the support design in the form of

- design block size
- loading condition
- spatial variability of ground condition
- rock mass strength, shear strength
- discontinuity spacing
- discontinuity orientation and

In the implementation phase of support design occur in the form of

- variation in installation quality
- adherence to patterns and spacing
- human errors in the application of applying the correct support standard
- not identifying a change in ground conditions

It is important to recognize that in geotechnical engineering, including in underground rock engineering, many of the risk sources or hazards arise from geotechnical uncertainty or error. The nature of the uncertainty and the errors that provide the sources of geomechanics risk in geotechnical engineering has been discussed by different authors. For example, Einstein and Baecher (1983) classified the sources of uncertainty as:

- inherent spatial and temporal variability
- measurement errors (systematic or random)

- model uncertainty
- load uncertainty; and
- omissions

Baecher and Christian (2003) and others have described these sources of uncertainty as being aleatory or epistemic.

a) ***Aleatory uncertainty*** is the irreducible randomness or variability associated with phenomena that are naturally variable in time or space, even when the system is well known. The discontinuity geometries and the mechanical and hydraulic properties of rock masses provide good examples of this natural variability.

b) ***Epistemic uncertainty***, on the other hand, arises from limitations in our fundamental knowledge or understanding of some aspects of a problem. According to brown (2017) this is sometimes termed ***conceptual uncertainty*** and may be reflected in the use of inappropriate models in analyses, for example.

Recently, Hadjigeorgiou and Harrison (2011) provided a valuable account of uncertainty and the sources of error in rock engineering. In discussing the use of rock mass classification schemes in the design of underground excavations, they identified two groups of errors.

- The first group consists of errors intrinsic to the classification scheme used, including errors of omission, errors of super fluousness, and errors of taxonomy associated with the requirement to select a particular classification rating value for a geo-mechanical property.
- The second group of errors is associated with implementation, and includes errors of circumstance, errors of convenience, errors of ignoring variability, and errors of ignoring uncertainty.

2.2.2 Common risks associated with tunneling

Risks associated with tunneling process can be classified as[17]:

- design risks
- construction risks
- external risks
- environmental risks
- organization risks
- project management risks
- right of way risks

1. Design risks

Design risks are related with design problems such as:

- design errors and omissions
- design process takes longer than anticipated
- stakeholders request late changes
- failure to carry out the works in accordance with the contract design

2. Construction risk

Construction risks are happening during construction phase due to many reasons (see section 2.2 above). The common hazards and potential risks in most, if not all, tunnels under construction are [19];

- tunnel instability – rock or earth falls and rock bursts
- changing conditions – strata and stress field fluctuations
- limited space and access for excavation and supporting system
- lack in level of expertise – even long-term tunnellers may lack experience in certain specialized aspects or methods
- air contamination or oxygen depletion
- fire or explosion problem
- close proximity to electrical supplies and circuits
- use of compressed air and high pressure hydraulics
- projected particles from rock breaking, drilling or cutting
- manual handling like large scale materials handling, spoil out, and materials and equipment
- uneven surfaces or difficult environmental surface such as wet or other slippery surfaces
- overhead seepage, ground and process water
- ground gas or water inrush
- contaminated groundwater
- reduced visibility while excavating long tunnels
- loss of power, including lighting and ventilation
- high noise levels and vibration

3. External risks

External risks can be occurring due to external factors which are obligation to the project manager or workers too [11].

- new stakeholders emerge and request changes
- public obligations
- laws and local standards change
- tax changes
- increasing cost of materials

4. Environmental risks

Among the risks which caused by changing environmental condition are [11];

- air contamination or oxygen depletion
- uneven surfaces or difficult environmental surface such as wet or other slippery surfaces
- overhead seepage, ground and process water
- ground gas or water inrush
- contaminated groundwater

5. Organization risks

Organization risks are happens during tunnel project due to lack of proper organization of the project [11]. Some of these are;

- Inexperienced workforce and staff turnover
- Lack of protection safety control on a construction site
- Delaying in delivery system
- Lack of well-organized and incorporate all departments

6. Project management risks

In the absence of project management team and guidance different risks could be occur and it is difficult to control it [11].

- Failure to comply with contractual quality Requirements
- Scheduling errors, contractor delays
- Project team conflicts
- Absence of an expertise in risk management

7. Right of way risks

The alignment of the tunnel might be cross different places that need permission from the responsible organization, so that could lead to delay to construction and other risks. Some of the risks which related to right of way are [11];

- Expired temporary construction permits
- Contradictions in the construction documents
- Presence of utility system

All these risks which are classified above can be happened at different phase of the tunnel construction project. it is very necessary knowing that at which phase what kind of risk could be happen, this helps to control it early before happing or to mitigate it if occurs already.

Accordingly that, the risks are mentioned which are associated with each tunneling phase as shown below.

a. During feasibility study

Tunnel construction is a complex project which needs feasibility study before designing phase [34]. During feasibility study the necessary information should be gathered otherwise it makes the design incorrect. Some of the risks that could be because of poor feasibility study are;

- in appropriate background information for the design
- poor environmental impact assessment
- insufficient data for preliminary design

b. During preparing contract and tendering

Some of the risks that could happen during the preparation of tendering are [26];

- poor selection or pre-qualification of contractors for tendering purposes
- inadequate time for the tendering
- not specifying risk management strategies
- delaying in submitting tenders

c. During design phase

Tunnel design is based on the data gathered from site investigation though different methods, so during design risks can occur. Some of the risks faces during design phase of the tunnel construction are;

- design errors and omissions
- design process takes longer than anticipated
- stakeholders request late changes to the design modification
- Failure to carry out the works in accordance with the contract agreement

d. During excavation

The most common hazards that exist in excavation of tunnel include [29]:

- cave-ins or excavation collapses
- face collapse including risks from changing ground conditions, mixed face and preferential excavation of soft ground leading to risk of settlement
- falling of excavated material
- slips, trips, and falls of rock faults
- exposure to dust and hazardous atmospheres
- flooding/water hazards
- blasting fumes and dust
- being hit by fly rock from road header or scaling activities
- moving plant and components causing crush, nip or shear injuries
- restricted operator visibility and communication from blocking view and loud continuous noises
- fire from flammable liquids and materials
- exposure to high pressure liquids or gases and high level of noises
- air contamination from excavation dust or exhaust emissions
- radiation rays from construction laser
- ground vibrations and overpressure from blasting

e. During support installation

While providing support for the tunnel different failures could be happen due to many reasons such as; improper calculating standup time and selecting inaccurate support type. The installation technique also influences the support strength. Some of the risks associated during supporting system are [29];

- rock falls or tunnel collapse when installing ground support
- dust from drilling rock bolts
- collapse of fresh shotcrete
- collapse from localized or general thawing or ineffective freeze due to moving ground water
- underground structure blowout or damage
- poorly designed or commissioned systems leading to injury or loss of life
- eye or skin contact with grout which causes chemical burns, poisoning and other toxic effects

f. During operation phase

When the tunnel is under operation phase accidents can occur such as;

- fire accidents
- aging of tunnel surfaces
- accidental collisions
- drainage problems

2.3 Risk management for tunnel construction

Tunneling risk can be defined as an exposure to the possibility of favorable or unfavorable effects on the tunneling project's goal (e.g., construction cost, time, or quality) as a consequence of a possible or an unforeseen incident [36]. Tunneling projects are often faced with several types of risk that typically do not exist or are not as important in other, more conventional construction works. The primary source of tunneling risk is geologic uncertainty. Subsurface conditions cannot be identified with certainty regardless of how sophisticated the adopted site exploration methods may be. Thus, successful tunneling project management requires a risk management technique that can identify, analyze, and respond to the associated risks systematically and effectively.

2.3.1 What is risk management?

i, Risk management

Risk management is the systematic process of [34]:

- identifying hazards and associated risks, through Risk Assessments, that impact on a project's outcome in terms of costs and programs, including those to third parties
- quantifying risks including their program and cost implications
- identifying pro-active actions planned to eliminate or mitigate the risks
- identifying methods to be utilized for the control of risks
- allocating risks to the various parties to the Contract

ii, Project risk

Project risk is defined as the combination of the consequence (or severity) of a 'hazard' and its likelihood, that is: Risk is a function of the consequence/severity of a hazard and the likelihood of occurrence of the hazard.

iii, Hazard

Hazard in tunnelling is defined as an event that has the potential to impact on matters relating to a project which could give rise to consequences associated with:

- health and safety
- the environment
- the design
- the program for design
- the costs for the design
- the construction of the project

- the costs associated with construction

Risk management is the systematic process of planning for, identifying, analyzing, responding to, and monitoring project risks. It involves processes, tools, and techniques that will help the project manager maximize the probability and results of positive events and minimize the probability and consequences of adverse events as indicated and appropriate within the context of risk to the overall project objectives of cost, time, scope and quality. Project risk management is most effective when first performed early in the life of the project and is a continuing responsibility throughout the project's life cycle [34].

Risk management is one of the nine knowledge areas propagated by the Project Management Institute (PMI). The PMBOK® Guide recognizes nine knowledge areas typical of almost all projects. The nine knowledge areas are [33]:

i. project integration management
ii. project scope management
iii. project time management
iv. project cost management
v. project quality management
vi. project human resource management
vii. project communications management
viii. project risk management
ix. project procurement management

Although these knowledge areas are all equally important from a project manager's point of view, in practice a project manager might determine the key areas which will have the greatest impact on the outcome of the project.

Each PMI knowledge area in itself contains some or all of the project management processes.

For example, project risk management includes [33]:

I. risk management planning
II. risk identification
III. qualitative risk analysis
IV. quantitative risk analysis
V. risk response planning
VI. risk monitoring and control

Risk management is probably the most difficult aspect of project management. A project manager must be able to recognize and identify the root causes of risks and to trace these causes through the project to their consequences. Furthermore, risk management in the construction project management context is a comprehensive and systematic way of identifying, analyzing and responding to risks to achieve the project objectives [32].

2.3.2 Importance of risk management

Construction projects can be unpredictable. Managing risks in construction projects has been recognized as a very important process in order to achieve project objectives in terms of time, cost, quality, safety and environmental sustainability [40]. Project risk management is an iterative process. The process is beneficial when is implemented in a systematic manner throughout the lifecycle of a construction project, from the planning stage to completion.
The use of risk management from the early stages of a project, where major decisions such as choice of alignment and selection of construction methods can be influenced, is essential [18]. The benefits of the risk management process include identifying and analyzing risks, and improvement of construction project management processes and effective use of resources.
Risk management is essential in tunnel design and construction. There is a potential for major accidents in tunnels both while the tunnels are being constructed and during operation of the completed tunnel. The major accidents which have occurred in recent years merely emphasize this issue. Thus, it is important that systematic risk management is implemented in tunnel projects in order to ensure an adequate level of safety in a cost-efficient way [34].

2.3.3 Risk management process

Risk management is an essential tool for eliminating or mitigating the consequence of risk in construction projects. The risk management life cycle consists of four major steps: risk-identification, risk-analysis, risk-response, and risk monitoring and evaluation. Risk-identification entails defining four risk components, namely, risk-sources, risk-factors, risk-events, and risk-impact [39].

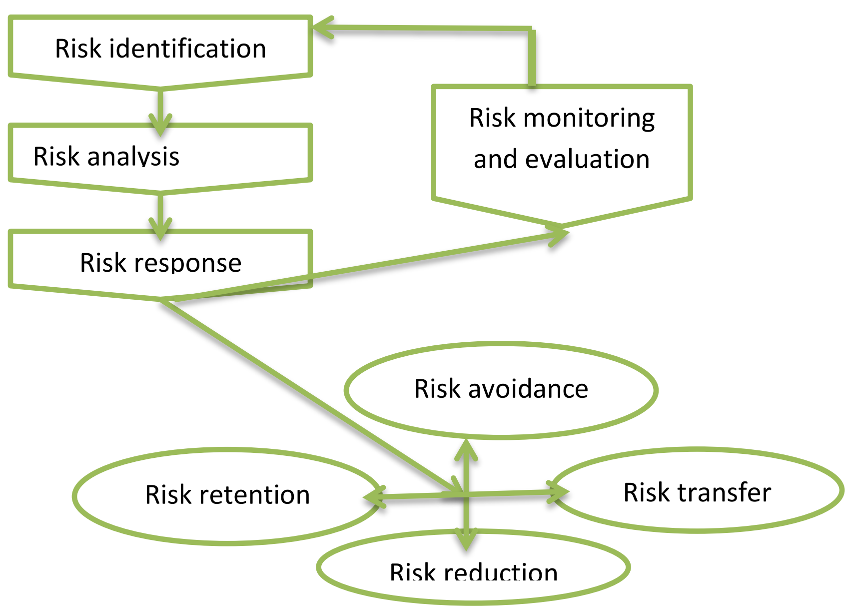

Figure 2 Risk management life cycle [39].

2.3.4 Tunneling risk identification

The first step in risk management process is identifying the risk of the construction project. The process of identification may rely upon [25]:

- a review of world-wide operational experience of similar projects drawn from the literature with written submissions from partner companies
- the study of generic guidance on hazards associated with the type of work being undertaken
- discussions with qualified and experienced staff from the project team and other organizations around the world

It is important to identify the potential risks in a structured process. A suggestion for grouping is proposed below.

General risks:

- contractual disputes
- insolvency and institutional problems
- authorities interference
- third party interference
- labour disputes

Specific risks:

- accidental occurrences
- unforeseen adverse conditions
- inadequate designs, specifications and programs
- failure of major equipment, and
- substandard, slow or out-of-tolerance works

The risks above have been grouped into general risks and specific risks. The specific risks should be considered for each part of the project; whereas the general risks may be considered generally for each contract [39]. For identifying the risks it is very important to know the risk factors that causes for the risk severity and occurrence. Risk factors can be external factors or internal factor as described in figure 3.

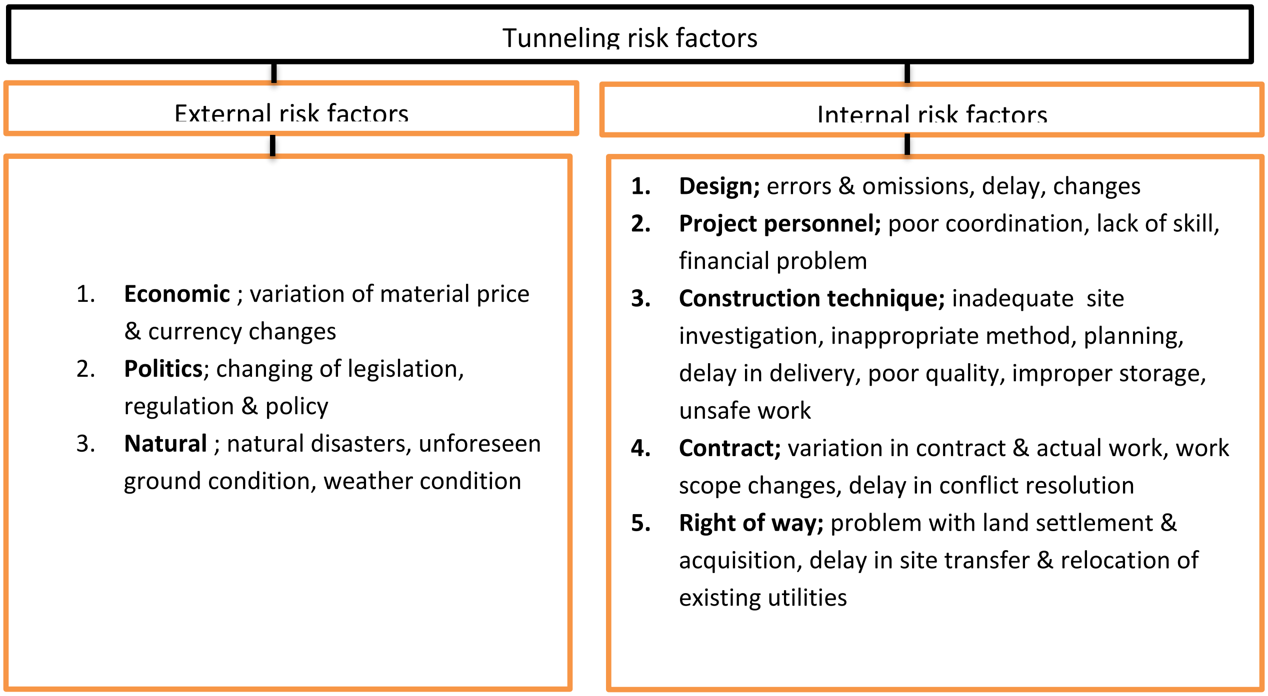

Figure 3 Tunneling risk factors [39]

2.3.5 Risk analysis

Risk analysis is the process of developing an understanding of each of the risks identified in the previous risk identification step. It provides an input to decisions on whether or not risks need to be treated, and on the most appropriate and cost-effective risk treatment strategies. It involves consideration of the sources of risk, their consequences and the likelihood of those consequences occurring. Risks are usually analyzed and evaluated by combining their likelihoods and consequences. Risk analyses may be qualitative, semi-quantitative or quantitative [39].

The following paragraphs provide brief overviews for some of the risk analysis and evaluation tools that are commonly used in tunneling works [36].

a) Fault tree analysis (FTA)

This method Identifies, quantifies and represents, in diagrammatic form, the faults and failures, and the combinations of faults and failures that can lead to a major hazard or event. It may be used either with or without quantifying the probabilities of events occurring.

b) Event tree analysis (ETA)

This method of analysis technique provides a systematic mapping of realistic event scenarios having the potential to result in a major incident, and the relationships, dependencies and potential escalation of events with time. It also provides numerical estimates of the likelihoods of occurrence of the component events and of the escalated event.

c) Consequence or cause-consequence analysis

This is a combination of fault tree and event tree analysis. The outcome is a diagram displaying the relationships between the causes and the consequences or outcomes of an incident. This technique is used most commonly when the failure logic is simple because a diagram combining fault and event trees can become quite complex.

d) Bowtie diagrams

Bowtie diagrams show how a range of controls may eliminate or minimize the likelihood of occurrence of specific initiating events that may generate risk, or reduce the consequences of an event once it has occurred. Bowtie diagrams, originated as a technique for analyzing safety incidents, but are also useful for analyzing other types of complex risks and for communicating key risks and critical controls Quinlivan and Lewis (2007).

e) Probabilistic risk analysis (PRA),

Including Monte Carlo and other types of simulations, is perhaps the most widely used method of quantitative risk analysis in geotechnical engineering (Baecher and Christian, 2003; Fenton and Griffiths, 2008).

f) Decision analysis,

Decision tree analysis, is a structured format used to analyze or assess the outcomes of decisions or choices made, based on the available information. Many decisions made in underground construction involve significant uncertainty.

g) Multi-risk analysis

This method is an approximate computational method of calculation for cases involving multiple statistically independent risks or hazards that are each treated as stochastic variables. It provides a method for dealing with uncertainty and may be used in estimating costs in tunneling.

h) Analytical hierarchy process (AHP)

This approach is used to address ill-defined and ill-structured problems in decision making and risk assessment. It is a mathematical technique for multi-criterion decision-making that allows decision alternatives to be ranked based on preferences through pair-wise comparisons Saaty, (1980); Taroun and Yang (2011). This technique has been used relatively widely in the Chinese construction industry, sometimes in combination with other approaches Deng and Zhou, (2010); Zhou et al. (2006) [36].

2.3.6 Risk response

Risk Response is the process of developing options, and determining actions to enhance opportunities and reduce threats to the project's objectives. It focuses on the high-risk items evaluated in the qualitative and/or quantitative risk analysis.

The project manager and the team members identify which strategy is best for each risk, and then design specific action(s) to implement that strategy. Strategies for Negative Risks or Threats include [34]:

- **Avoid**. Risk avoidance involves changing the project plan to eliminate the risk or to protect the project objectives (time, cost, scope, quality) from its impact.
- **Transfer**. Risk transference requires shifting the negative impact of a threat, along with ownership of the response, to a third party.
- **Mitigate**. Risk mitigation implies a reduction in the probability and/or impact of an adverse risk event to an acceptable threshold.
- **Acceptance**. Risk acceptance requires while it is either not possible to eliminate that risk from a project or the cost in time or money of the response is not warranted by the importance of the risk.

2.3.7 Risk monitoring and controlling measures

Risk monitoring and control keeps track of the identified risks, residual risks, and new risks. It also monitors the execution of planned strategies on the identified risks and evaluates their effectiveness [34].

Risk control measures; for each risk identified, control measures must be considered in the following order.

a) The first obligation is to eliminate risk e.g. choose a different construction method. Elimination gives the best level of safety and must be adopted unless it is not reasonably practicable. Where elimination is not reasonably practicable, risk must be minimized to the lowest level reasonably practicable by applying controls in the order.

b) Substitute the hazard giving rise to the risk with a hazard that gives rise to a lesser risk. For example, redesign the work process so that less hazardous equipment, materials or substances are used; use less toxic chemicals or less flammable substances; have products packaged in smaller quantities if lifting them poses risks.

c) Isolate the hazard from the person put at risk. For example, set up a restricted work area; reduce emissions and noise from machinery through venting and containment or isolation barriers.

d) Minimize the risk by engineering means. For example, ensure that exposed moving parts on equipment are adequately guarded and lock out devices are fitted; reduce noise levels from machinery by installing dampening methods like mufflers; look for better safety design features on equipment.

e) Minimize the risk by administrative means. For example, organizing the way tasks are done can sometimes reduce exposure to risks; job rotation and task variety can reduce the risks associated with repetitive manual handling tasks; provide appropriate safety training, instruction or information; use written safe work procedures; develop preventative maintenance schedules to identify and fix faulty machinery, use hazard warning signs.

f) Use personal protective equipment (PPE).For example, use safety eyewear and footwear, hearing protective earplugs or muffs, safety helmets, respirators. PPE is the least preferred solution to OHS problems because it does not really address the hazard but merely provides a shield to protect the worker. However, in some cases, it may be the only practicable means.

2.4 Guideline for risk management

To manage the risks which could happen during different phase of the tunnel projects it is necessary to develop guideline.

The four terms guideline, procedure, standard and policy have different meanings. Guideline is simply to give an overview of how to perform a task. Procedure tells us step by step what to do while standard is the lowest level control that cannot be changed. Policy is a high level statement uniform across organization [7].

Guideline is;

- Guide' + 'Lines' meaning Instructions for guiding purposes only
- A piece of advice on how to act in a given situation
- Recommended but Non Mandatory Control

Figure 4 Guideline definition [7].

CHAPTER 3 CURRENT TUNNEL PRACTICES IN ETHIOPIA

3.1 General

In Ethiopia modern tunnel construction has been recently used in hydropower projects, road projects and railway projects. Till now many hydropower tunnels had been constructed and there are also many railway tunnels which are planned to be constructed in the future. Among the constructed tunnels are;

- hydropower projects such as Fincha hydropower, Beles hydropower, Tekeze hydropower, and the three Gilgel Gibe hydropower projects
- road tunnels of tarmaber are also among the constructed tunnel projects at debresina region

Now days National Railway Network of Ethiopia (NRNE) has planned railway projects which involve tunnel construction. This includes;

  - ❖ Awash-Weldiya railway line project: which has fourteen tunnels along the route
  - ❖ Weldia-Mekelle railway line project: which has six tunnels along its route

3.2 Type of tunnels

Based on their purpose tunnels in Ethiopia can be classified into three groups.

1. railway tunnels
2. road tunnels
3. hydropower tunnels

3.2.1 Railway tunnels

Railway tunnels are understructures which are constructed for the purpose of rail transport mode. Railway tunnels are recent practices for Ethiopia. This is because it asks advance technology and big capital. Now days the national railway network of Ethiopia (NRNE) has planned railway projects which involve tunnel construction. Among the tunnels which are already constructed and those which are under construction include:

- Awash-Kombolcha- Haragebeya railway project
- Weldiya-Mekelle railway project
- Minillik II square railway tunnel(AARLT)

1. Awash Kombolcha haragebeya railway project

a. General description of the tunnels

The Awash-weldiya railway project is one of routs planed by the ERC to connect the northern part of Ethiopia with Djibouti port. The contract is given to the Turkish contractor (yapi Merkezi) and at this time almost 60% of the work has been completed.

According the design plan Awash-Weldiya railway route line project has fourteen tunnels which are constructing in two phases. In the first phase half of the tunnels have been constructed, and the remaining will be constructed in the second phase [3].

Table 1 Awash-Weldia railway tunnels [3]

No	Tunnel name	shape	Width(m), height(m)	Length(km)	Geological condition
1	Tunnel 01	Horse shoe	8.6, 10.7	0.321	trachyte formation
2	Tunnel 02	Horse shoe	8.6, 10.7	0.189	Kemise formation
3	Tunnel 03	Horse shoe	8.6, 10.7	0.385	Ashangi formation
4	Tunnel 04	Horse shoe	10.7, 11.5	1.530	Ashangi formation
5	Tunnel 05	Horse shoe	8.6, 10.7	0.403	Kemisefoemat ion
6	Tunnel 06	Horse shoe	8.6, 10.7	0.322	Kemise formation
7	Tunnel 07	Horse shoe	8.6, 10.7	0.287	Ashangi formation

b. Geological condition

The tunnels cross three rock formations identified as ‘ Ashangi formation, Kemise formation and Trachyte formation’ composed by black and dark grey, fine grained to coarse grained basalt and volcanic clastic sediments and rhyolite and ignimbrite tuff and ash. In the portals areas some cohesive soils, due to sedimentation or weathering process, are present. In general the rock mass is fractured and some main faults are present along the alignment. Besides close the portals the rock mass has a certain degree of weathering [3].

c. Construction method

The tunnels are constructed by conventional excavation method. Conventional excavation method consists in sequential-section advancement combined, if required with pre support and / or pre-confining technique ahead of tunnel face. The excavation is performed by using ‘drill and ballast’ method and depending on the local formation geological characteristics, where the quality of the rock mass is low, with backhoe type excavators with impact hammers. The excavation is done by one step (full face excavation) or different steps (partial excavation) based on the support class i.e. on the typology of adopted support type [3]. The support class depends on the RMR rock mass classification.

Figure 5 Visiting Tunnel construction at AKH railway project

d. Tunnel construction phases

The tunnel construction method consisted of three steps, and the typical work flow is as shown figure below.

Step1.Forepoling or umbrella arch

Step2. Mechanical excavation or drill and blasting and hauling

Step3. Temporary support (steel rib+ shotcrete+ rock bolts)

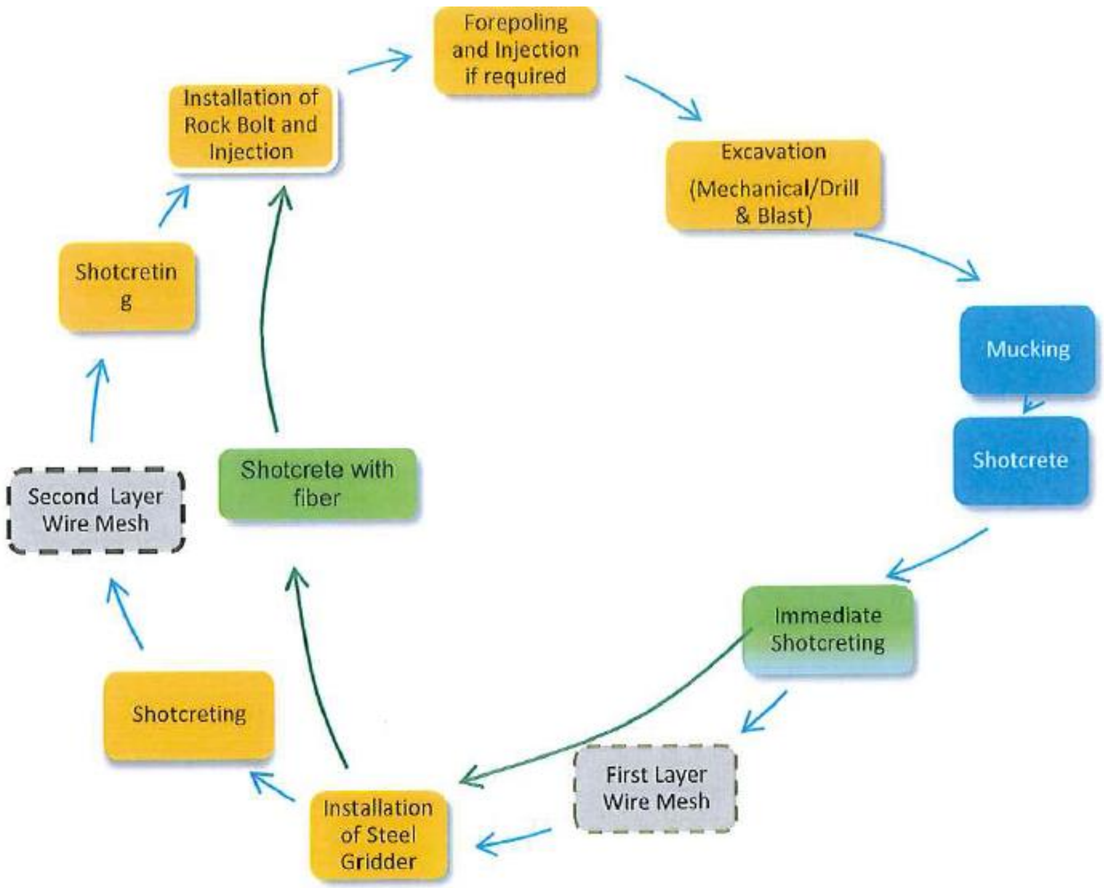

Figure 6 Working flow of tunnel excavation and supporting operations [3].

1. Fore poling / Umbrella arch

Fore poling is the application of auxiliary support element which is installed in the longitudinal direction of the excavated tunnel in order to give additional strength to the soil before excavation is started. This method is also helps to prevent excess deformation and collapse. In the Awash-Kombolcha-haragebeya railway project the Fore polling in use was 26 diameter rebars and 1.5 inch steel pipes [3].

Umbrella arch is also has the same application as fore polling method, and they are installed before excavating the tunnel face. Holes enough large for umbrella arch are drilled and after that the pipes are installed.

Figure 7 Pipes for umbrella arch purpose

2. Mechanical excavation

The excavation is done in three phases in order to reduce the deformation and at the same time to achieve the stabilization of the face. Three phases are;

- First the top part is excavated which is called top heading excavation
- Second the two side of the tunnel face is excavated which is called bench excavation
- Third the last step is bench excavation which is the bottom part of the tunnel face.

All the three excavation phases are carried out by track excavators, but in some places hard rock faces blasting technique are applied [3].

3. Supporting system

The supporting systems used in the tunneling of AKH rail project are;

- Steel fibers/ wire mesh are used to prevent the rock falls and it is installed before shotcreting
- Still lattice girder to support the excavated ground and they are connected by bolts in correct place.
- Shotcrete are placed after the steel structures are installed the cured properly to gain the desired strength.
- Rock bolts were installed to enhance the stability and durability of the ground surface. Rock bolt increases the shear strength and quality of the rock surface.
- Grouting is then applied for all rock bolts, fore polling and umbrella application.

Figure 8 Lattice girder (a, d), Rock bolt (b) and Steel ribs(c)

4. Muck handling and transportation

The surplus material produced during excavating loaded and are disposed to the dump place, so that the tunnel have to be clean.

5. Controlling and monitoring the tunnel

A Geotechnical instrument monitoring is installed in order check the deformation and ground settlement. The deformation is observed by optical prism which is placed in different position of the tunnel face. The tunnel must be checked during the excavation and during its service time.
The control of tunnel deformation is an intrinsic aspect of tunnel excavation method, which depends on adjustment of the primary support or final lining. The optical prisms are installed in five position of the tunnel as shown in the figure below. Location of convergence sections are depends on the RMR value of the ground surface. The follow up is carried out daily at least for

one week then after that according the data it is possible to be taken reading once every 15 day (AKH, 2016).

Table 2 Relation between convergence section & RMR [3]

Convergence section distance(m)	RMR value of the rock
30-50	>60
20-30	40-60
10-20	20-40
5-10	<20

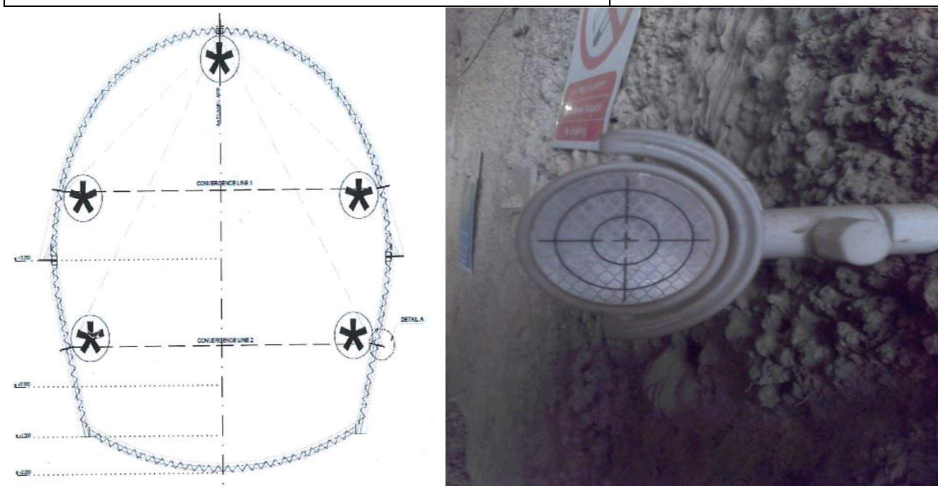

Figure 9 Installation of Optical prism, [3]

6. Safety works

The entire tunnel works have constructed based on the project safety, health, environmental and social plan developed by the client (ERC), and contractor (Yepi Merkezi).

The safety department conducted employers training program and all workers are trained before start work and also by wearing protecting equipments such as helmet, safety shoe, goggles and vests. Access to the excavated area is protected by making temporary fences and warning signs are placed at different location of the tunnel[3].

The slopes for the excavation are arranged in order to reduce the soil slide and collapse of the surface during work. The portal faces are supported properly and the drainage system also constructed based on the topography of the environment. All excavation of tunnels is managed according the plan, so that risks are minimized as the required one.

Based on the project criteria knowledge and skills required for excavation work should be competent on the following[3];

- hazard identification & risk assessment for tunnel stability
- taking measures to control risks of tunnel collapses
- safe work practices and procedures for installing control measures

- how to plan and prepare for working in tunnels
- how to identify soil types and the factors which can affect the tunnel stability

2. Weldiya-Mekelle railway route

a. General description of the tunnels

For the Awash –Mekelle railway route, the section between Awash &Weldiya was awarded to the Turkish contractor Yapi Merkezi while the section between Weldia & Meekelle was awarded to the chinese contractor CCCC. The Chinese company is responsible for the construction of about 260 km long rail line connecting Hara Gebeya town – via the nearby bigger city of Woldia, to Mekele city. This route will extend further north to Shire town in the next phase of the New National Railway Network plan. Within the chinese section, there are six tunnels namly Aroley 1, Aroley 2, Addionfito, Serghiem, Mai celfo and Kokele, with Mai celfo and kolele (as shown below) are the longest tunnels[3].

Table 3 Profile of Weldiya- Mekelle railway tunnels

No	Tunnel name	Length(km)	Diameter(m)	Construction method
1	Aroley 1tunnel	1.98	8x8	Drill and blast method
2	Aroley 2 tunnel	0.994	8x8	Drill and blast method
3	Addionfito tunnel	0.179	8x8	Drill and blast method
4	Serghiem tunnel	0.121	8x8	Drill and blast method
5	Maicelfo tunnel	3.662	8x8	Drill and blast method
6	Kolele tunnel	2.07	8x8	Drill and blast method

b. Construction method

The tunnels along the Weldiya-Mekelle route of railway projects are constructed by sequential excavation and drill and blasting system.

The steps of construction and supporting system are similar to the Awash-Kombolcha Haragebeya railway project, and the entire tunnel works have been constructing based on the project safety, health, environmental and social plan developed by the client (ERC), contractor (CCCC)[3].

c. Common risks

The common risks during the construction phase are;

- Water seepage/percolation
- Rock falls
- Ventilation and lighting problem
- Noise and dust problem

d. Remedial measures

Some of the remedial measures taken by the project engineers are;

- Designing dewatering system through geotechnical modeling
- Installation of drainage pipes
- Pre-treating and consolidating the ground
- Scaling to minimize risk of the rock falls
- Using PPE and hearing protection equipment
- Using dust suppression sprays, spotters and eyeglasses.
- Providing electric generator and mechanical ventilation system
- Arranging the blasting time at the absence of workers
- Shotcreting the excavated surface
- Providing proper support system based on the average stand uptime
- Safety works in general

e. Safety works

Safety works are take place during the construction of the tunnels by the safety department team. Some of the safety measures are;

- Training the employee before start working
- Hiring an experienced technicians on operating tunneling machines
- Protecting the excavation places by different barriers
- Making warning sign around the entrance
- Supervising the workers if they have wear PPE
- Continuous monitoring of the excavated face
- Portals are protected by shotcreting and rock bolts
- Surface drainage is properly designed to prevent collapse of the tunnel

Due to these all safety measures risks at the Weldia-Mekelle railway project are reduced as the required level.

Figure 10 Kolele railway tunnel

Figure 11 Aroley railway tunnel

3. AALRT route

1. Background

Minillik II square tunnel is part of the Addis Ababa light rail transit route. The tunnel is constructed by Chinese company. Minillik II square tunnel is constructed by cut- cover method. This method has been chosen cause of it is located in urban area and short in length. It has around 300m length and 5m height by 7m width.

2. Common risks

During the construction period there wasn't any registered accident; this might be due to the type of construction method used, the time allocated and because of proper risk management plan of the company. The problem was during the construction time the road was crowded, so that people and car couldn't move safely that is due to location of the site is urban center. The other related risk was noise and dust pollution to the people who using around the site.

Figure 12 Menellik II tunnel construction.

3. Remedial measures

The company tries to work day and night in order to solve the problems listed above and in order to finish quickly. This was good management and decreases the direct or indirect impact on the environment and people. Some of the remedial measures are;

- Warning/safety signs are posted around the excavated surface
- Fence work to prevent from entering to the site
- Traffic controlling

3.2.2 Road tunnels

1. Background

Road tunnels are constructed for the purpose of road transport. Even though Ethiopia is a terraineous country, due to the economy or technology reasons there aren't long road tunnels. Most of the roads were constructed during the invasion of fascist Italy around 1935 to access the country. Among the tunnels built at that time are Tarmaber tunnel and Weldiya tunnel.

2. Common risks

The tunnel was deteriorated due to its long age, surface drainage and degradation of the surface around the portal. The internal upper face was leaking water, and the road surface was deteriorated that wasn't confortable for transport.

3. Remedial work

Tarmaber tunnel is maintained by the Chinese construction group company because of its long age, the tunnel face was under some problems like seepage and surface deterioration. At this time the maintenance is completed and now it is giving the service. The maintenance work includes inside part of the tunnel by installation of steel girder and shotcreting it, and the portal surface by stone wall and grouting the surface to prevent the entrance from degradation. The road part is also maintained so that it is smooth for the traffic flow.

Figure 13 Tarmaber tunnel after maintained

3.2.3 Hydropower tunnels

Hydropower tunnels are constructed for the purpose of electric power generation. Those tunnels are important in order to convey the water to the power generation house. In Ethiopia until now many hydropower tunnels are constructed and some are currently under construction.

These hydropower tunnels include in this study are:

- Gilgel Gibe I hydropower tunnel
- Gilgel Gibe II hydropower tunnel
- Gilgel Gibe III hydropower tunnel
- Tana Belece hydropower tunnel

1. Gilgel Gibe I

a. Back ground

Gibe I is located at about 260 km south-west of Addis Ababa on the road to Jimma town.

b. Construction method and support system type

Gibe I headrace tunnel was constructed by Conventional drilling and blasting method and its length is about 9300m. The Powerhouse was constructed underground, in a 68,000m3 Cavern, 98m long, 38m high and 18m wide, excavated inside the massive limestone rock on the right bank of the river [1].

Table 4 Gigel Gibe I tunnel geometries and lining properties [1]

Tunnel geometries	
Purpose	Generation of power
Construction method	Conventional drilling and blasting
Length	9.3km
Diameter	5.5m
Design internal pressure	min.2 bar max.7 bar
Design discharge	100.5m/s3
Lining geometric characteristics	
Segment type	Reinforced segment lining
Segment thickness	0.25
Segment width	0.5

c. Ground condition

The common ground formation of the tunnel alignment was basalt rock type, bituminous material and soft ground.

d. Nature and type of failure

- No recorded failure during the construction period

2. Gilgel Gibe II

a. Back ground

The Gibe II is located at 240 km south-west of Addis Ababa, coordinates (7°45′25″N, 37°33′44″E). The project channels the water discharged from the Gilgel Gibe I dam through a 26km long tunnel and a steep drop directly to the valley of the Omo River (Google).

b. Construction method and support system type

The 25.8 km long tunnel has been excavated by two 7 m diameter Double Shield TBMs [4].

Table 5 Gilgel Gibe II tunnel properties [4]

Tunnel geometries	
Length	25.8km
Diameter	6.3m
Design internal pressure	min.2 bar max.7 bar
Design discharge	100m/s3
Lining geometric characteristics	
Segment type	n.4 hexagonal
Segment thickness	25cm
segmental liningoutside diameter	6.8mm
segmental lining final internal	6.3mm
Segment width	1.6mm

c. Ground condition

The nature of the ground was basically formation of omo basalsts and jima volcanic [4].

- *Weathered brecciated basalt*: greenish grey, dark to light grey and brown in color, highly joined and fractured, moderately to highly weathered, weak to moderately strong and slicken sided basalt with reddish brown, highly weathered to decompose. Joint planes are filled with calcite and clay infillings.
- *Decomposed Basalt:* reddish brown, highly weathered to decomposed, weak and slicken sided basalt, grey to greenish grey, smooth to slicken sided highly weathered tuff-clay.

d. Nature and type of failure

- Construction failure
- At the chainage 4+196 from intake heading at the end of October 2006, the TBM was pushed back as consequence of the sudden extrusion and collapse of the tunnel face against the cutter head and the front shield.

e. Possible cause of failure

- The existence of complex anticlinal structure over the line of the tunnel, which could not have been deduced from rock exposed in the tunnel but was later exposed in the open cut excavation after the diversion of the tunnel alignment
- The degeneration of the rock within the anticlinal structure built up heavy loading on the arch ring and side walls
- Additional excavation in the tunnel increased the stresses in the already overstressed rock in the side walls

f. Consequences

- The TBM has been pushed back more than 60 cm and displaced laterally more than 40 cm.

Figure 14 Tail TBM shield damaged and bent [4]

- As consequence, severe damages occurred to the shields, the cylinders and the last 7 segment rings installed behind the TBM.

Figure 15 Lining segments moved and severely damaged [4].

- In June 2007 a collapse of the front face started at the left Exploratory Adit, producing three controlled leaching of about 3500 m3 of mud, which filled the Adit and about 80m of the power tunnel.

Figure 16 Mud in the Exploratory Adit [4].

g. Remedial measures

- The mud was removed from the power tunnel and partly only from the left exploratory Adit;

Figure 17 Extracting of mud: a) from the power tunnel b) from exploratory Adit. [4]

- The back-up was extracted from the tunnel;

Figure 18 Consolidated mud filling the Power Tunnel [4]

- more powerful drilling equipment was positioned behind the TBM shields (having removed the back-up of the TBM);
- The construction of a new exploratory Adit on the Right side (40m behind) then started.
- Completion of the Back Chamber through a concave shot-concrete wall, reinforced with horizontal steel ribs HEB200.

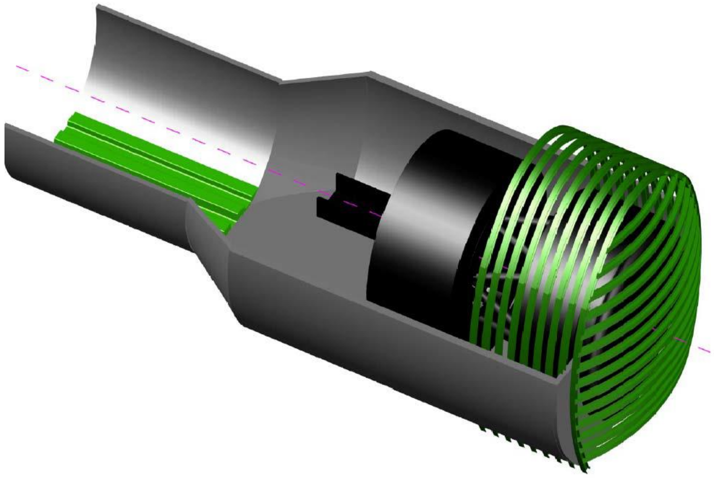

Figure 19 3D Model of the Rescue Chamber built to recover the TBM [4]

- TBM Dismantling inside the Back Chamber and carrying outside
- Refurbishing and reconstruction of the TBM (in the external yard)

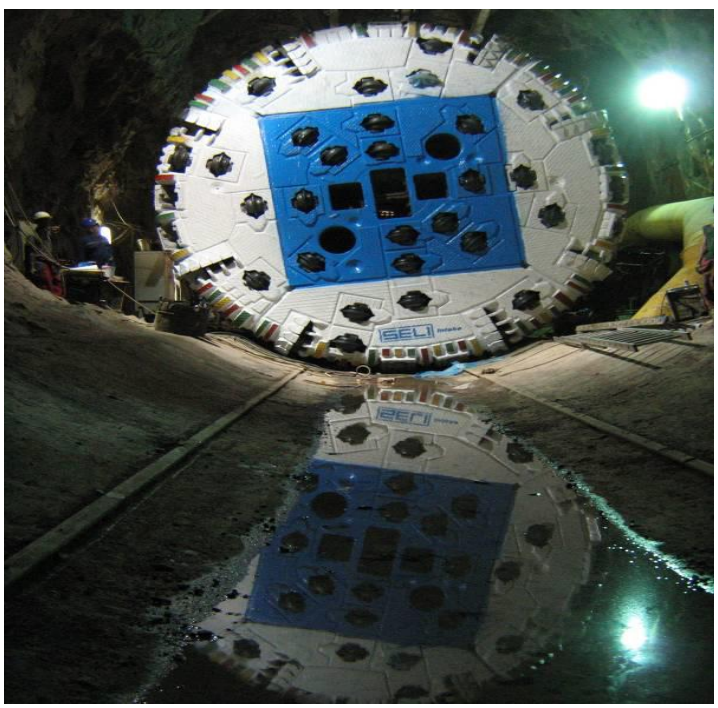

Figure 20 The TBM was re-assembled and excavation along the new alignment restarted [4].

- construction of a new assembly chamber and TBM launching chamber
- segmental lining dismantling and casting of a concrete plug in the Power Tunnel
- to facilitate TBM steering at the excavation resuming and to reinforce the pillar between the two tunnels, in the transition zone the old tunnel has been filled with concrete
- resuming of the Intake drive excavation along a new alignment at ch.3+805
  The new Power Tunnel alignment was chosen maintaining a minimum distance from the explorative Right Adit.

3. Gilgel Gibe III

a. Back ground

The Gibe III hydroelectric power project is located within the Gibe-Omo River Basin, in the middle reach of the Omo River approximately 450 km south of Addis Ababa.

b. **Construction method and support system type**

The construction method used in Gilgel Gibe III hydropower tunnels was drill and blast. The tunnels were excavated in two phases, i.e., top heading and then bench excavation techniques.

Table 6 Gilgel Gibe III tunnel properties **[38]**

Tunnel Type	Length (m)	Diameter/Height (m)	Average x-section Area (m2	Shape of Tunnel	Intake Elevation (m)	Outlet Elevation (m)
Right DT	1222	14/15	175	Horse shoe	680	674
Central DT	1026	14/15	175	Horse shoe	680	674
Left DT	969	8	57	circular	687	681
Left PT	1050	12/12.6	126	Horse shoe	780	775
Right PT	975	12.3/12.6	126	Horse shoe	780	775

c. Ground condition

The Gibe III project site is located in the jima volcanic formation, a thick succession of basalts and sialic rocks, divided into jima Rhyolites. In the project area, the formation is constituted mainly by trachytes, basalts and pyroclastics. The main trachyte formation along the tunnel alignments are;

- Slightly weathered trachyte (SW-T),
- Unweathered trachyte (U-T), and
- Brecciated trachyte (Br-T).

d. Nature and type of failure

The failures which happen during the construction phase are [38];

- Rock wedge failures at chainage 0+843 during shotcreting lately in the right manifold of the power tunnel.
- Rock and shotcrete wedges failure at chainage 0+175, 0+178 and 0+185 and

- Major collapse of tunnel section occurred at chainage 0+175 in the central river diversion tunnel during the construction.

e. Possible cause of failure

The possible Causes of collapse include[38]:

- Excessive delays in the installation of the required ground excavation supports.
- Installation of improper ground excavation supports.
- Convergence monitoring was not installed.
- Drainage holes were not installed.

f. Consequences

- worker lost due to the rock failure
- Damage in equipment

g. Remedial measures

- The fallen mass is mucked out
- Support is provided
- Drainage holes are repaired

4. Beles hydro power

a. Back ground

Beles hydropower plant is located in the Amhara region, about 150km from the town of Bahir Dar on the south-western bank of Lake Tana.

b. Construction method and support system type

Table 7 Beles hydropower tunnels [38]

Tunnel geometric properties		
Tunnel type	Headrace tunnel	Tailrace tunnel
Shape	Circular	circular
Diameter(m)	8.1	8.07
Length(Km)	12	7.2
Construction method	TBM	TBM
Support type	Precast concrete and the annulus backfilled with pea-gravel and mortar.	Lined with an open type parallel ring rhomboidal segmental system with a peagravel and mortar annular fill.
Thickness(mm)	300	300

c. Ground condition

The tunnel ran through a variety of ground formations with about 10km passing through hard granite rock of up to 350MPa in compressive strength and intersected by local faults, and another 1.8km of loose soils, basically lake deposits, through which the machine advanced with a daily output of about 15-20m [38].

d. Nature and type of failure

The failures which happen during the construction phase are;

- At about half way through the headrace tunnel a massive failure of the rock fragments

e. Possible cause of failure

The possible Causes of collapse [38], in brief, include:

- weak geological formation, such as presence of voids
- heaps of loose rubbles in the face and around the cavity
- Method of construction; such as using dual-mode tunnel boring machine (TBM) instead of double shield earth pressure balanced (EPB).

f. Consequences

- The double shielded TBM was broken
- The massive failure of the tunnel face blocked the TBM’s cutter head
- It brought the progress to standstill.

g. Remedial measures

Among the many options available to deal with the difficulty, SELI (sub-contractor) chose to employ polymer resins and a three-stage process to secure the heading and resume TBM advance [38].

- First, the void ahead and above the cutter head was filled with high expansion polymer resins that support the void to prevent further material falling. TIS-foam DRY K (a high expansion ratio organo-silicate resin) was injected through a set of appropriately positioned pipes through the TBM cutter head and at sufficient volume to completely fill the cavity.
- Secondly, the crown and face area was consolidated using TIS-sill STAB (a low expansion ratio organo-mineral resin). TIS-sill STAB has exceptional mechanical resistance and adhesion and was injected again through cutter head and via pipes positioned appropriately to consolidate the heap of loose rubble in the face and around the cavity.
- Following that a hand-mined heading was advanced out above the shield to remove rocks and free up the cutter head, being assured at all times that all ahead is stabilized and made safe.

CHAPTER 4 QUALITATIVE RISK ANALYSIS FOR TUNNELING IN ETHIOPIA

In the previous chapter of literature review all about risk definitions, common risks in tunneling, risk causes and impacts, risk management process, procedures, risk identification, and controlling measures are reviewed. This chapter focuses on analyzing the tunneling risks in Ethiopia using qualitative risk assessment method, and by using the standard procedures of qualitative analysis, risks are identified and risk matrix is developed in order to classify the risk level based on the frequency and impact of the risk.

4.1 Risk analysis

Risk analysis is a structural process which identifies both probability and extent of adverse consequences arising from activity. Risk analysis includes identification of hazards and description of risks i.e. probabilities and consequences. It provides an input to decisions on whether or not risks need to be treated, and on the most appropriate and cost-effective risk treatment strategies. It involves consideration of the sources of risk, their consequences and the likelihood of those consequences occurring [36] Risks are usually analyzed and evaluated by combining their likelihoods and consequences. Risks can be analyzed by using different tools may be qualitative, semi-quantitative or quantitative (see section 2.3.5).

4.2 Qualitative risk assessment

Qualitative risk analysis is the application of methods for ranking the identified risks according to their potential effect on project objectives. This method is one way of determining the importance of addressing specific risks and guides risk response measures.

Qualitative Risk Analysis assesses the priority of identified risks using their probability of occurring, the corresponding impact on project objectives if the risks do occur, as well as other factors such as the time frame and risk tolerance of the project constraints of cost, schedule, scope, and quality [11].

Sometimes experts or functional units assess the risks in their respective fields and share these assessments with the team. Across the same project the definitions that will be used for levels of probability and impact should be the same.

In general qualitative analysis includes;

- Hazard identification through brainstorming, reviewing previous projects, risk screening teams etc.
- Identification Classification of the frequency, consequence and risk levels of the identified hazards.
- Identification of the risk response methods.
- Documentation of risk management work in risk registers.

The organization’s management, project customer or sponsor has an important role in the Qualitative Risk Analysis process.

- The project sponsor defines for the risk analysis lead and team, the levels of impact on time, cost, scope and quality that would qualify a risk as having a very low, low, moderate, high or very high impact on each objective.
- The project sponsor determines the combinations of probability and impact that make a risk low, moderate and high priority for each objective in light of the definitions just mentioned.

Once the definitions are in place, team members assess the identified risks' probability and impact and then put them into high, moderate, and low risk categories for each project objective (time, cost, scope, quality). They rank risks by degrees of probability and impact, using the definitions in place, and include their assessment rationale.

Team members revisit qualitative risk analysis during the project's lifecycle. When the team repeats qualitative analysis for individual risks, trends may emerge in the results. These trends can indicate the need for more or less risk management action on particular risks, or whether a risk mitigation plan is working [11].

4.3 Qualitative Risk assessment procedures

In general qualitative risk analysis for tunneling work includes the following procedure

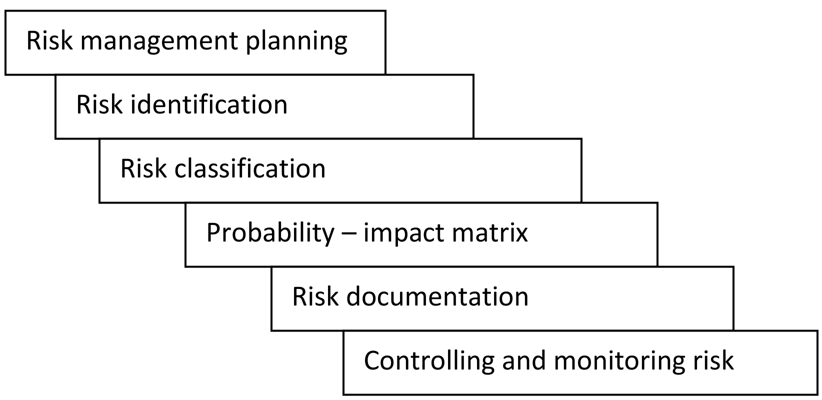

Figure 21 Qualitative risk analysis procedure

1. Risk Management Planning

Risk Management Planning is the process of deciding how to approach and conduct the risk management activities for a project.

The Risk Management Planning process should be completed early during project planning, since it is crucial to successfully perform the other processes.

The risk management plan identifies and establishes the activities of risk management for the project in the project plan (RMP).

2. Risk identification

Risk identification involves identifying potential project risks. Risk Identification produces a deliverable project Risk Register; where risks are identified that may affect the project's ability to achieve its objectives.

The potential risks are identified by using the following methods;

- Lessons learned from past tunnel risks.

- The risk breakdown structure, suitably tailored to the project.
- The sample risk list provided by different authors
- Own knowledge of the tunnel project or similar projects.
- Consulting with others who have significant knowledge of the project or its environment.
- Questionnaire form (see appendices A) and interviewing those who involve in the tunnel construction.

Risk identification is an iterative process because new risks may become known as the project progresses through its life cycle and previously-identified risks may drop out.

It is important to specify the risk correctly. For instance, a risk has a cause and, if it occurs, an impact on a project objective. The risk statement structure that should be followed in specifying identified risks is: Because of the cause or condition, a risk may occur, leading to an impact on the project's cost, time, scope and or quality.

3. Classification of the consequence, frequency and risk level

3.1 Risk probability and impact assessment

Probability and impact may be described in qualitative terms as very high, high, moderate, low and very low.

Risk probability is the likelihood that a risk will occur while risk impact is the effect on project objectives if the risk occurs, which may be a negative effect (threat) or a positive effect. In this study the negative effect (threat) of the risk is applied to the overall risk of the project. The levels of probability and impact are assessed by questioner survey. The participants include subject matter (area of risk) experts and project team members.

In this research questionnaire is prepared (see appendix A) and the data had been filled by the responsible body. The risks for this study are categorized in to seven main categories and each group has division as shown in the Table 11.

Table 8 Likelihood categories relative to risks during tunneling

Likelihood	Level	Descriptor
	1	Very rare
	2	rare
	3	possible
	4	likely
	5	frequent

Table 9 Risk impact level on the tunneling construction

Impact	Level	Description
	1	Very low
	2	Low
	3	Medium
	4	High
	5	Very high

Table 10 risk classification based on their likelihood and impact sample

Categories	Likelihood 1(rare)-5(frequently)	Impact 1(very low)- 5(very high)
Design risks		
1. Design errors and omissions	2	4
2. Design process takes longer than anticipated	2	3
3. Stakeholders request late changes	1	2
4. Failure to carry out the works in accordance with the contract	2	4
External risks		
1. New stakeholders emerge and request changes	1	2
2. Public objections	2	2
3. Laws and local standards change	1	2
4. Tax change	2	2
5. construction cost increasing	3	2
Environmental risks		
1. Environmental analysis incomplete	2	3
2. air contamination or oxygen depletion	1	4
Organizational risks		
1. Inexperienced workforce and staff turnover	3	3
2. Delayed deliveries	3	2
3. Lack of protection on a construction site	3	4
Project management risks		
1. Failure to comply with contractual quality Requirements	2	4
2. Scheduling errors, contractor delays	2	2
3. Project team conflicts	1	3
Right of way risks		
1. Expired temporary construction permits	1	3
2. Contradictions in the construction documents	1	3
Construction risks		
1. cave-ins or excavation collapses	2	5
2. construction equipment failures	3	4
3. Falling of excavated material	4	4
4. changing conditions – strata and stress field fluctuations	2	3
5. tunnel instability – rock or earth falls and rock bursts	2	4
6. high noise levels and vibration	5	3
7. excessive seepage and ground water inflow	2	4
8. fire or explosion problem	1	5

4. Developing Probability X impact risk rating matrix

A probability X impact matrix is constructed that assigns risk rating (low, moderate or high) to risks based on combining probability and impact scales of a risk on a project objective.

This matrix determines which combination of probability and impact result in a risk's being classified as high risk (red condition), moderate risk (yellow condition), and low risk (green condition).

The risk score helps to put the risk into a category that will guide risk response actions [31]. Risks with high probability and high impact are likely to require further analysis, including quantification, and aggressive risk management (both negative and positive effects). Lower risks would require less emphasis and it may be enough to include them in a watch list for monitoring. The matrix below shows the probability- impact rating ratio for specific risk.

Table 11 Risk evaluation matrix

Likelihood [1(rare)-5(frequently)]	Impact [1(very low)- 5(very high)]				
	1	2	3	4	5
5	Medium	High	High	Very high	Very high
4	Medium	Medium	High	Very high	Very high
3	Low	Medium	Medium	High	High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium

According the matrix shown above the level of the risk is classified or ranked as follows;

- value from 1-4 low risk level
- value from 5-9 medium risk level
- value from 10-15 high risk level
- value above 16 is very high risk level

The risk will be treated based on its rank of risk level, and the recommended risk treatment is described in the table below.

The risk matrix presented above is intended as a basis for decision on acceptability for each hazard identified and by controlling the magnitude of the individual risk from the individual hazard, the total risk involved in the tunneling work will be controlled.

Table 12 Risk level Vs Decision criteria

Risk level/score	Decision criteria/risk treatment method
Very high (intolerable)	Risks cannot be justified except in extraordinary circumstances
High (unacceptable)	Drive risks towards the broadly acceptable region
Medium (moderate)	Residual risk is tolerable only if further risk reduction is impractical
Low (acceptable)	Risk reduction not likely to be required

5. Developing risk registered document based on the risk level

I. The output of the qualitative analysis

The questionnaire was surveyed for the awash-kombolcha hara gebeya railway project. According the data gained from fifteen respondents/experts, the risk level is analyzed. According [2] the analysis is done by calculating the average risk value from the questioner of the respondent and the result is documented in table form as shown below. The alphabets (A, B, C….) indicate the respondents and the numbers are likelihood/impact level values.

Table 13 Risk likelihood analysis

Risk categories	Respondent's/ likelihood															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Avg.
1.Design errors and omissions	1	2	1	2	1	1	1	1	3	1	2	1	2	1	1	2
2.Design process takes longer than anticipated	3	3	3	1	3	1	2	3	2	1	1	1	2	2	2	2
3.Stakeholders request late changes	1	4	2	1	2	1	1	2	1	1	2	1	1	2	3	1
4.Failure to carry out the works in accordance with the contract	1	1	1	2	1	3	3	2	3	2	2	2	1	1	1	2
5.New stakeholders emerge and request changes	1	3	2	1	1	1	1	2	1	1	1	1	1	2	1	1
6. Public objections	4	4	3	3	2	2	1	1	2	2	2	3	2	2	1	2
7.Laws and local standards change	1	2	1	1	1	1	1	1	2	3	2	2	1	1	1	1
8.Tax change	1	3	2	3	2	1	2	2	1	3	3	3	2	2	2	2
9.construction cost increasing	2	4	2	2	2	2	2	3	2	2	2	3	2	3	4	2
10.Environmental analysis incomplete	1	2	3	1	2	2	1	1	1	1	1	4	3	3	1	2
11.air contamination or oxygen depletion	1	1	1	2	2	1	1	1	2	2	2	2	1	1	2	1
12.Inexperienced workforce and staff turnover	1	2	2	3	2	3	2	3	1	2	2	3	2	3	3	2
13.Delayed deliveries	3	3	3	2	3	2	2	3	1	3	2	2	1	1	2	2
14.Lack of protection on a construction site	1	4	3	4	1	4	4	4	3	3	3	4	2	1	2	3
15.Failure to comply with contractual quality Requirements	1	3	2	1	2	2	1	3	2	2	2	1	3	2	1	2
16.Scheduling errors, contractor delays	1	3	1	3	1	2	1	2	2	2	3	1	1	1	1	2
17.Project team conflicts	2	4	2	2	3	1	1	1	2	1	1	2	2	2	1	2
18. Expired temporary construction permits	1	3	1	1	2	1	1	1	2	1	1	1	1	2	1	1
19.Contradictions in the construction documents	1	2	1	1	3	1	1	1	1	2	2	2	1	1	1	1
20.cave-ins or excavation collapses	1	3	2	4	1	3	4	1	3	2	2	3	3	4	3	2
21. construction equipment failures	2	4	1	3	2	4	2	2	3	4	4	4	2	3	2	3
22.Falling of excavated material	1	3	3	4	2	4	2	4	3	2	3	3	2	1	1	2
23.changing conditions – strata and stress field fluctuations	5	4	2	3	5	3	3	3	2	1	1	1	3	1	2	3
24.tunnel instability – rock or earth falls and rock bursts	1	2	3	2	1	3	2	3	2	2	2	3	4	1	2	2
25.high noise levels and vibration	4	4	4	4	3	5	3	4	3	5	5	4	3	3	3	4
26. excessive seepage and ground water inflow	5	3	3	4	2	4	2	2	1	3	4	3	2	1	4	3
27.fire or explosion problem	1	2	1	1	2	1	1	3	1	3	1	3	2	2	2	2
28.improper/unfair /delay in resettlement of the land owners	2	2	2	2	3	3	2	2	1	2	2	2	3	3	3	2
29.conflict with the land owners	1	1	1	1	2	2	2	2	2	1	2	1	1	1	1	1

Table 14 Risk impact analysis

Risk categories	Respondent's/ impact															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Avg.
1.Design errors and omissions	3	5	4	5	4	4	5	5	3	4	3	3	5	5	5	4
2.Design process takes longer than anticipated	3	4	5	4	2	3	4	3	2	2	3	2	2	3	3	3
3.Stakeholders request late changes	4	3	2	3	4	2	2	2	2	3	3	4	4	3	3	3
4.Failure to carry out the works in accordance with the contract	5	5	3	5	5	3	3	5	3	3	4	2	4	4	4	4
5.New stakeholders emerge and request changes	4	2	3	2	4	1	2	3	2	2	3	3	3	3	2	4
6.Public objections	3	3	1	3	3	3	2	4	4	2	2	2	3	1	2	3
7.Laws and local standards change	3	5	2	3	2	2	3	4	2	3	3	2	2	3	3	3
8.Tax change	1	2	2	4	2	2	2	3	4	2	2	3	3	3	2	3
9.construction cost increasing	3	3	4	2	3	3	2	3	2	2	2	3	2	3	3	3
10. Environmental analysis incomplete	4	4	2	4	4	4	3	5	3	3	4	5	4	4	4	4
11.air contamination or oxygen depletion	4	5	4	3	3	3	4	5	4	4	3	4	3	5	4	4
12. Inexperienced workforce and staff turnover	3	5	2	2	4	3	3	4	3	3	4	4	3	4	3	3
13. Delayed deliveries	4	4	3	2	2	4	3	3	2	2	4	3	4	4	3	3
14. Lack of protection on a construction site	5	3	5	5	4	3	2	5	4	4	3	3	2	2	4	4
15. Failure to comply with contractual quality Requirements	4	3	5	5	3	4	3	3	5	2	4	4	4	4	5	4
16. Scheduling errors, contractor delays	4	4	3	3	2	2	2	4	2	3	3	4	2	5	3	3
17. Project team conflicts	3	4	2	2	3	3	3	4	5	4	4	3	3	2	4	3
18. Expired temporary construction permits	3	4	2	4	2	1	1	4	3	1	1	2	2	3	3	2
19. Contradictions in the construction documents	3	3	2	2	4	1	2	4	2	3	1	2	2	2	2	2
20.cave-ins or excavation collapses	5	4	5	4	4	4	4	5	4	5	5	5	4	4	4	5
21.construction equipment failures	4	5	4	4	3	4	3	5	3	4	3	4	4	4	5	4
22. Falling of excavated material	4	3	5	4	3	2	2	5	3	4	4	4	3	3	4	3
23.changing conditions – strata and stress field fluctuations	1	5	3	5	2	3	3	4	5	3	5	3	5	5	5	4
24.tunnel instability – rock or earth falls and rock bursts	5	3	3	4	5	3	4	4	5	4	4	4	5	5	4	4
25.high noise levels and vibration	4	2	2	3	4	3	2	5	2	2	3	3	4	3	3	3
26.excessive seepage and ground water inflow	5	5	5	5	3	3	3	2	2	3	4	5	5	4	4	4
27.fire or explosion problem	5	5	4	5	3	4	4	4	3	3	4	5	4	3	4	4
28.improper/unfair /delay in resettlement of the land owners	2	3	2	2	3	3	3	3	3	1	2	3	1	4	4	3
29.conflict with the land owners	3	4	4	3	5	4	3	2	2	2	4	2	3	4	3	3

II. Risk register updates

After the qualitative analysis has done risks will be registered based on;

- relative ranking or priority list of project risks by their group category (high, medium, and low)
- lists of risks requiring response in the near term (Urgent risks)
- list of risks for additional analysis and response
- lists of low priority risks
- trends in qualitative risk analysis results

As the analysis is repeated, a trend for particular risks may become apparent and can make risk response or further analysis more or less urgent (important).

Risk Registers shall be 'live' documents that are continually reviewed and revised as appropriate and available for scrutiny at any time.

Table 15 Risk register document

Activity/ service tunnel	Risk type	Consequence of risk	likelihood	Impact level	Risk level	Management and controlling method	Responsible
Construction of tunnel	1. cave-ins or excavation collapses	Injuries, death workers & damage to goods &progress delay	2	5	M	PPE, training workers, proper maintenance supervising,& keep swing area	Safety/site engineer, site Forman
	2. construction equipment failures	>>	3	4	H	>>	>>
	3. Falling of excavated material	>>	2	3	M	>>	>>
	4. changing conditions – strata and stress field fluctuations	Excessive deformation & settlement	3	4	H		
	5. tunnel instability – rock or earth falls and rock bursts	Injuries, death workers & damage to goods &progress delay	2	4	M	PPE, training workers, proper maintenance, supervising,& keep swing area	Safety/site engineer, site Forman
	6. high noise levels and vibration and dust	Hearing problem	4	3	H	Wearing noise protecting equipment& masks	Safety engineer/ Forman & the workers
	7. excessive seepage and ground water inflow	Damage to structure of the tunnel	3	4	H	Qualified professions, PPE, continuous monitoring	Site engineer/ project manager
	8. fire or explosion problem	Injuries, death workers & damage to goods &progress delay	2	4	M	PPE, training workers, regularly checking & storing the chemicals , gases in proper place, alarms	Safety/site engineer, site Forman
Designing tunnel geometry and support type	1. Design errors and omissions	Quality problem, financial loss, time loss	2	4	M	Qualified designer, Revising & redesign	Designer/ office engineer
	2. Design process takes longer than anticipated	Delay to construction time	2	3	M	Qualified designer	Designer/ office engineer
	3. Stakeholders request late changes	Delay to construction time	1	3	L	Experienced stakeholders	client
	4. Failure to carry out the works in accordance with the design contract	Quality problem, financial loss, time loss	2	4	M	Experienced contractors	contractors
Managing and identifying risks	1. Failure to comply with contractual quality Requirements	>>	2	4	M	Experienced contractors	contractors
	2. contractor delays,	Financial losses	2	3	M	Experienced Contractors	contractors
	3. Scheduling errors	Financial losses	3	3			
	4. Project team conflicts	Delay to work, personal effect	2	3	M	Managing the conflict	Managers/team leaders
During Organizing the work flow	1. Inexperienced workforce and staff turnover	Quality effect, safety problem	3	4	H	Qualified workforce	Managers & site engineers
	2. Delayed deliveries	Delay the construction phase	2	3	M	Qualified manager & contractors	managers & contractors
	3. Lack of protection on a construction site	Serious injuries, death to workers	2	5	H	PPE, training workers	Safety engineer/ Forman

Environmental analysis	1.	Environmental analysis incomplete	Environmental damage	2	3	M	Experienced engineer	Client/ government
	2.	air contamination or oxygen depletion	Health problem	1	3	L	Inside the tunnel by wearing masks, alarms, preventing the gases from escaping to the env't by d/nt techniques	Safety engineer
	3.	incomplete analysis on social and culture of the environment	Loss of culture & heritages	2	3	M	Communicating with the religious or cultural leaders	Client/ government
Resettlement or right of way issues	1.	improper/unfair /delay in resettlement of the land owners	dissatisfaction to the people, conflict, delay	2	3	M	Resolving the conflict in proper way	Client/ government
	2.	conflict with the land owners	>>	1	3	L	>>	Client/ government
Other external activities	1.	New stakeholders emerge and request changes	mismatching b/n the stake holders, less quality & delay	1	3	L	Experienced stake holders, by sharing experiences	The stakeholders
	2.	Public objections/challenges	Delay & access prohibit	2	4	M		
	3.	Laws and local standards change	Disagreement, dissatisfaction, Delays to the construction time	1	3	L	The client and contractor should resolve it reasonably	Client /contractor
	4.	Tax change	Additional cost to the contractor, financial crisis	1	4	L	Modifying the delivering system	Client /contractor
	5.	construction cost increasing	>>	3	4	H	Sharing the burden b/n the client & contractor	Client/contractor

The risks according their level of risk can be classified as shown the risk matrix table (15) below. The symbol represents;

C- For construction risk and the subdivisions is subscript in number

D- For design risk and the subdivisions is subscript in number

En-For environmental risks and the subdivisions is subscript in number

Ex-For external risks and the subdivisions is subscript in number

M- For management related risks and the subdivisions is subscript in number

O- For organizational risks and the subdivisions is subscript in number

R- For right of risks and the subdivisions is subscript in number

In Table 16, risk scores were found for all 27 events, by multiplying the severity of the event with the frequency level.

Risk Score = Severity (impact) x Probability (likelihood)

The regions marked with "green" colour in Table 16 emphasize risk scores at "acceptable" levels (1-4). In the same table, the regions marked with "yellow" colour display risk score levels described as "moderate" (5, 6, 7, 8, 9). In Table 16, the regions marked with "red" colour illustrate risk scores at "unacceptable" levels (10, 11, 12, 13, 14, 15) and at intolerable level for (>15) values.

Table 16 Risk matrix developed for 27 identified risks

Likelihood [1(rare)-5(frequently)]	Impact [1(very low)- 5(very high)]				
	1	2	3	4	5
5					
4			C_6		
3		D_2	M_3	O_1,C_2,C_4,C_7 Ex_5	
2			$O_2,M_2,M_4,$ En_1,En_3,C_3,R_1	$En_1,M_1,C_5,C_8,$ D_1,D_4,Ex_2	C_1,O_3
1			D_3,Ex_3,R_2,En_2	Ex_4	

The risk matrix developed above is based on the experts point of view and as the result indicates that most of the risks associated during construction phase of the tunnel are categorized into high risk level while most of risks are assigned in the medium level and other external risks are grouped the low risk level. Therefore the high risk level must be reduced to the acceptable level or different risk mitigation measures must be developed in order to control the risk impact on the project goals. According to the analysis result; likelihood, impact and risk level relationship can be described by using chart as shown below.

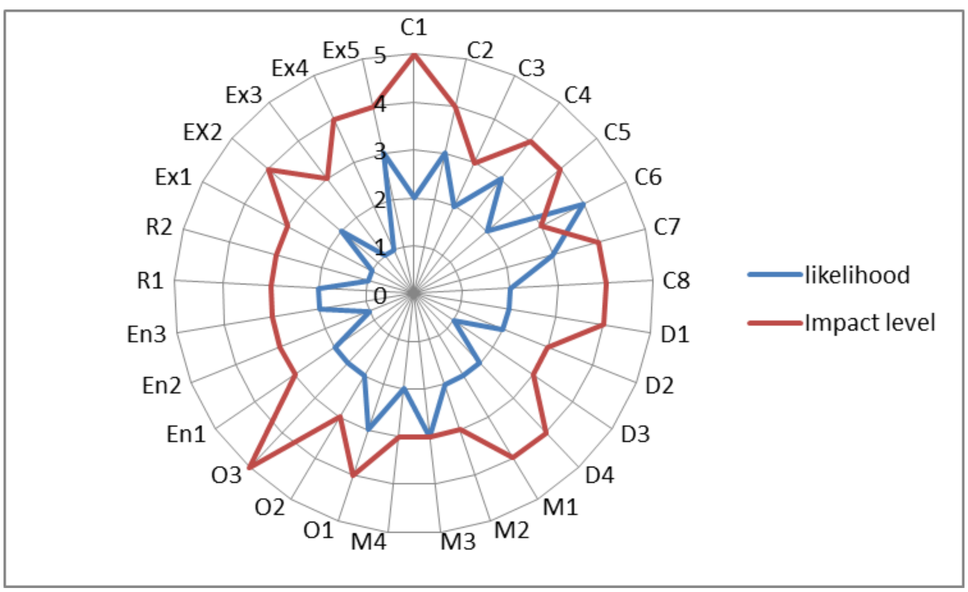

Figure 22 risk level classification

6. Identifying risk reduction and control measures

According the risk level, risks can be reduced, accepted, avoided, and controlled. Very high level of risks can't be justified except in extraordinary circumstances, while risk reduction not likely to be required for risks of low level. For the medium risk level is acceptable risk and controlling measures should be developed, while these in high risk rank should be reduced to the acceptable level. Some control measures are mentioned in the risk register, but the tunneling risk controlling measures are discussed broadly in chapter five.

For effective risk assessment it is important to have the following criteria;

I. Risk data quality assessment

The use of accurate data is necessary for a reliable qualitative risk analysis. Assessment involves examining the extent of understanding of the risk, data available about the risk and reliability of the data. The use of data of low precision data, for instance if a risk is not well understood, may lead to a qualitative risk analysis of little use to the project manager. It may be necessary to gather better data, so that the questionnaires are filled by those engineers who are assigned in different tunnel projects.

II. Risk urgency assessment

Some risks which occur during tunnel construction require urgent responses, so that urgency can be addressed by including time of response as an indicator of priority. Other indicators may include symptoms and warning signs, as well as the risk rating.

III. Alternative Risk response method

For the identified risk in the questioner survey the respondent was also asked which alternative risk response methods are better or used in the current tunnel construction. The alternative risk response method provided in the questioner were risk reduction, risk retention, risk transfer, risk elimination, contingency allowance. Risk reduction also divided in to acquisition of additional information, using physical protection, personal management, and work adjustment, while risk transfer divided in to subcontracting and construction insurance. From the questioner survey, the data is extracted and the result is summarized in the table form as shown below.

- (xxx) represents more than eight of the respondents select the alternative risk response method
- (xx) represents no of respondent b/n the range of three and seven
- (x) represents less than three respondents

Table 17 Alternative risk response data

Risk type	Alternative Risk response methods									
	R_t	R_{d1}	R_{d2}	R_{d3}	R_{d4}	T_1	T_2	E	C	N
1. Design errors and omissions			x	xxx				xx		
2. Design process takes longer than anticipated		xxx							xx	x
3. Stakeholders request late changes		xxx			xx					
4. Failure to carry out the works in accordance with the contract				xxx			xx	x		
5. New stakeholders emerge and request changes	x	xx			xxx					
6. Public objections(challenges)	x	xxx		xx						
7. Laws and local standards change	xxx								xx	x
8. Tax change					xxx				xx	x
9. construction cost increasing					xxx		xx		x	
10. Environmental analysis incomplete	x	xxx						xx		
11. air contamination or oxygen depletion		xxx						xx		
12. Inexperienced workforce and staff turnover								xx		
13. Delayed deliveries		xx	xxx					x		
14. Lack of protection on a construction site			xxx	xx						
15. Failure to comply with contractual quality Requirements	xx								xx	x
16. Scheduling errors, contractor delays				xxx				x	xx	
17. Project team conflicts			xx	xxx						
18. Expired temporary construction permits	x					xxx				xx
19. Contradictions in the construction documents					xxx			xx		
20. cave-ins or excavation collapses		xxx							xx	
21. construction equipment failures							x	xx	xxx	
22. Falling of excavated material			xxx				xx	x		
23. changing conditions – strata and stress field fluctuations		xxx					x			
24. tunnel instability – rock or earth falls and rock bursts			x				xxx			
25. high noise levels and vibration	xx		xxx				x			
26. excessive seepage and ground water inflow		xx		xxx					x	
27. fire or explosion problem				x			xxx		xx	
28. improper/unfair /delay in resettlement of the land owners	x	xxx					xx			
29. conflict with the land owners		xx	xxx					x		

Note: Risk response methods

R_{d1}: Risk reduction by addition information acquisition
R_{d2}: Risk reduction by physical protection
R_{d3}: Risk reduction by personnel management
R_{d4}: Risk reduction by work adjustment
R_t: Risk retention
T_1: Risk transfer by subcontracting
T_2: Risk transfer by construction insurance
C: Contingency allowance
N: Risk is not considered
E: Risk elimination (avoidance)

As the result indicates that, the choosing of the alternative risk response method is quite different for each tunneling work challenges, but while selecting the risk response method it is necessary to consider;

- project cost and characteristics
- project delivery system
- project payment method
- stakeholders risk policy
- contractors experience

Therefore based on the surveying data as shown on table 17 above, we can adopt the most mentioned alternative response method by the tunnel experts. Selecting the appropriate response method is necessary to control and manage risks.

CHAPTER 5 GUIDELINE FOR TUNNELING RISK MANAGEMENT

5.1 General

Tunnelling works impose risks on all parties involved as well as on those not directly involved in the project. The very nature of tunnel projects implies that any potential tunnel owner will be facing considerable risks when developing such a project. Due to the inherent uncertainties, including ground and groundwater conditions, there might be significant cost overrun, delay risks, safety risks and as well as environmental risks. As described in chapter three tunnel practices in Ethiopia there is a potential for large scale accidents during tunnelling work.

Systematic risk management technique is necessary thought out the project development and by using the guidance potential problems can be clearly identified such that appropriate risk mitigation measures can be implemented in a timely manner.

The use of risk management from the early stages of a project, where major decisions such as choice of alignment and selection of construction methods can be influenced, is essential.

The risk management for tunneling work can be grouped into four phases. i.e from the early planning stage up to operation time [35].

Phase 1: Early Design Stage (Feasibility and Conceptual Design)

Phase 2: Tendering & Contract Negotiation

Phase 3: Construction Phase

Phase 4: Operation/maintenance phase

In phase 1 the responsibility of establishing a risk policy and carrying out risk assessment is the owner's alone. In phase 2 the potential contractor has certain input to the tender regarding risk management, but the owner is still the primary responsible party. In phase 3 however, the primary responsibility moves on to the contractor to establish a risk management system and to carry out effective risk management. The owner should supervise, inspect and participate in this work. The owner should further continue to assess and mitigate risks not covered by the contractor.

It is important that the risk management is performed in an environment of good cooperation between the parties. To achieve this, partnering may be a valuable tool. The process of partnering may be formulated as an exercise in encouraging good communications between the parties. It may be a formula for minimizing cost to the owner while maximizing profit for the contractor and encompasses joint planning and problem solving, scheduling, mitigation of delays and value engineering. The process of "partnering" may therefore be seen as a risk mitigation measure for the owner and the contractor.

It is important to note that the success and benefits of implementing effective risk management depends on the quality of the identified risk mitigating actions and on the active involvement, experience and general opinion of the participants (owner, designers and contractors).

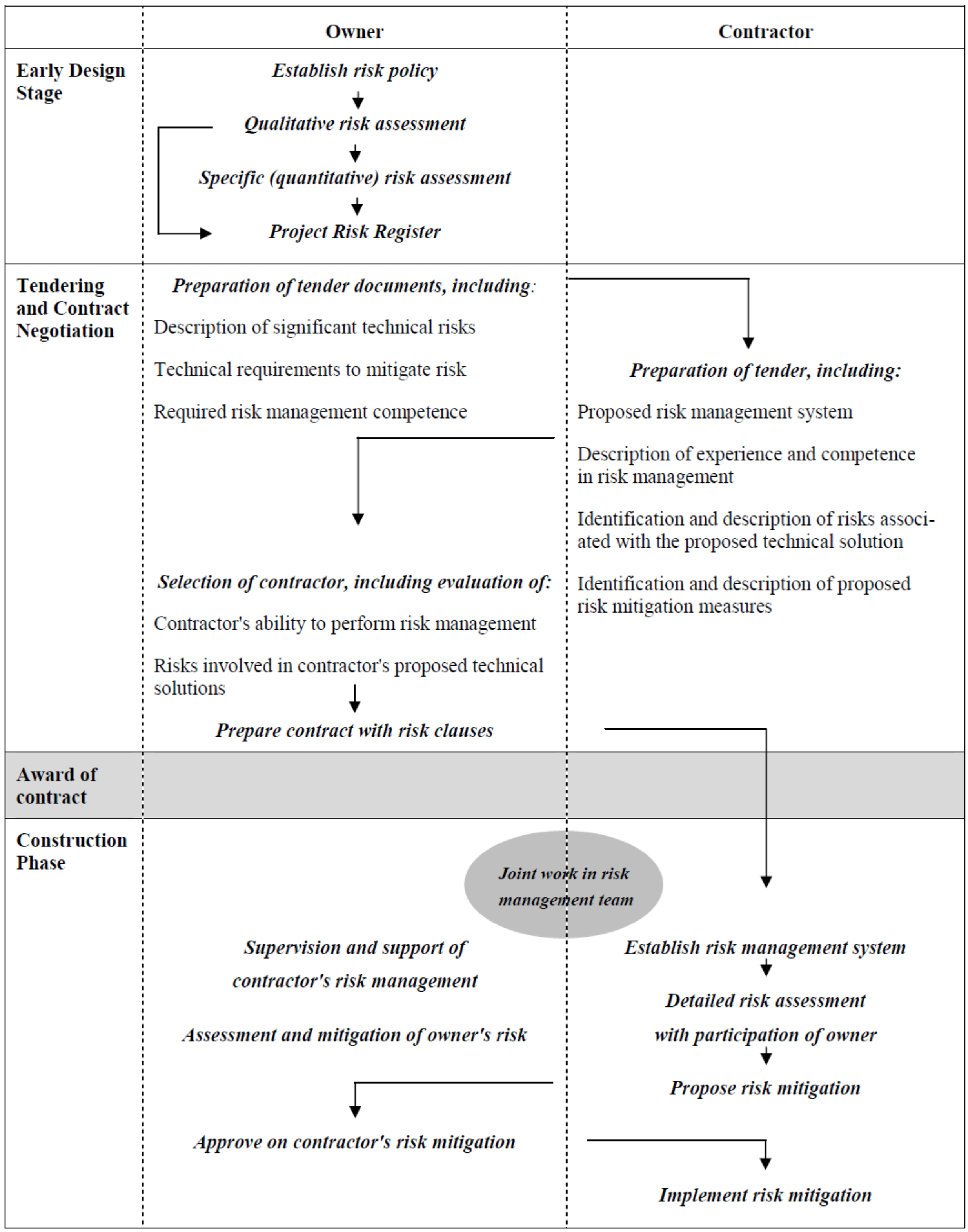

Figure 23 Risk management activity flow chart for owner and contractor [35].

5.2 Risk management at the early design stage

For effective risk management of a tunnelling project it is vital that risk management is begun as early as possible, preferably during the project feasibility study, planning and design stages. Many aspects of tunnel design influencing whether a tunnel is constructed safely, like tunnelling in rock or soft ground, are decided in the concept design stage. During this phase duty holders should consult and plan to manage risks which may occur when constructing, using and maintaining the tunnel.

To control Risks at the early design stage the following activities should be done [26, 35];

a. The designer must give the results of calculations, analysis, testing and examinations necessary to ensure the design is without risks to health and safety to the responsible person
b. The assumed geotechnical conditions used in the design should also be provided to the principal contractor by the designer to allow these to be monitored and compared with the actual conditions experienced during the tunnelling work.
c. Reviewing existing geological information and conduct a workplace investigation to determine whether existing information is accurate and sufficient.
d. Consulting with national bodies about environmental and geological conditions, mineral workings, and planning transport issues.
e. Reviewing specifications of the geological conditions assumed in the design by the designers.
f. Implement an inspection plan to compare the actual geological conditions as the excavation progresses with the assumed conditions.

Safe tunnel design and construction depends on pre-construction investigation of the ground conditions, the workplace and proper interpretation of this information [26].

Designers should be:

- provided with available and relevant information
- told of gaps in the information for planning and construction
- involved in collecting data during workplace investigations, and
- Included in on-site investigations.

Workplace investigations should consider the type, extent and location of the tunnelling work and local environmental conditions. The investigation should allow realistic assessments of different tunnelling designs and methodologies.

The workplace investigation should be carried out by suitably qualified and experienced people. The workplace investigation may include:

- investigating the Climatic and prevailing weather condition of the site
- understanding the topography location, condition and influence of existing structures, services and old workings of the workplace

- investigating Geophysical conditions such as; drilling boreholes or examining existing borehole results, laboratory assessment of soil and rock properties, rock cutting, dust production and blasting trials
- studying on the ground water conditions including location, volume and possible changes due to tunnelling and other activities

The workplace investigation will provide information to assist the geotechnical risk assessment of ground and other conditions.

According ITA working group the assessment should consider [26]:

- proper study on rock mass geology
- defining and explaining the exciting ground planes of weakness
- defining the mechanical properties of rock including the influence of planes on the rock mass
- investigating the in-situ rock stress field magnitude and orientation
- considering the induced rock stress field due to excavation
- selecting the potential rock failure mechanisms
- understanding the blast damage effects to the rock mass if blasting is being considered
- likely scale and nature of the ground behaviour e.g. movement
- investigating the possible effects on other work places or installations
- investigating if groundwater is presence and its quantity
- investigating the possible environment contaminants such as; hazardous gases like methane, liquids like industrial waste and solids like naturally occurring or dumped asbestos
- studying on the previous relevant experience and historical data for the area

At this stage the owner is responsible to establish risk policy, risk acceptance criteria, qualitative and quantitative risk assessment options.

1. Risk management policy

The identification of risks resulting from design and construction is an essential task early in a project. In order to form a common reference for all parties involved (e.g. the owner, designers, insurers and contractors) a construction risk policy should be established by the owner [35].

The owner of the tunnel project should establish risk management policy and the risk policy should be indicating;

- the Scope
- the risk objectives and
- risk management strategies

The scope should be incorporate risks to the;

- health and safety of workers, including personal injury and, in the extreme, loss of life,
- health and safety of third parties,
- third party property, specifically existing buildings and structures, cultural heritage buildings and above and below ground infrastructure,

- the environment including possible land, water or air pollution and damage to flora and fauna,
- owner in delay to the completion,
- owner in terms of financial losses and additional unplanned costs

The risk management objectives should incorporate;

- identification of hazards
- identification of measures to eliminate or mitigate risks
- implementation of measures to eliminate or mitigate risks where economically feasible or required according to the specific risk objectives or health and safety legislation

The risk management strategies should incorporate [16];

- a definition of the risk management responsibilities of the various parties involved (different departments within the owner's organization, consultants, contractors)
- a short description of the activities to be carried out at different stages of the project in order to achieve the objectives
- a scheme to be used for follow-up on results obtained through the risk management activities by which information about identified hazards(nature and significance) is freely available and in a format that can be communicated to all parties, which may best be accomplished by some form of comprehensive risk register
- follow-up on initial assumptions regarding the operational phase
- monitoring, audit and review procedures

2. Risk acceptance criteria

The risk objectives expressed in general terms in the owners risk policy should be "translated" into risk acceptance criteria suitable for use in the risk assessment activities planned to be carried out [16]. This may include:

- Risk acceptance criteria to be used in qualitative risk assessment.
- Risk acceptance criteria to be used in quantitative risk assessment.
- Those risks which are above the limit or below the limit should be reduced and between the limit shall be considered and mitigated based on the criteria.

3. Qualitative risk assessment

During the early design stage, a qualitative risk assessment should be carried out focused on the identification of potential hazards to the construction activities expected to be included in the project, and covering all types of risk noted in the construction risk policy [11].

The qualitative risk assessment should include:

- Hazard identification.
- Classification of the identified hazards.
- Identification of risk mitigation measures.
- Details of the risks in the project risk register indicating risk class and risk mitigation measures for each hazard.

The aim should be to identify all conceivable hazardous events threatening the project including those risks of low frequency but high possible consequence.

4. Quantitative risk assessment

In this quantitative risk assessment specific risk analysis method should use rather than general qualitative analysis in order to analyze the result. Therefore choosing the appropriate analyzing method is depends on the interest or different risk analysis criteria [16].

5.3 Risk management during tendering and contract negotiation

5.3.1Risk management during preparation of tender documents

The following risk management activities should be carried out during preparation of the tender documents [30]:

- Specification of technical and other requirements in the tender documents such that the risks are managed in accordance with the risk policy.
- The qualitative risk assessment carried out in the early design stages should be mentioned.
- Specification of requirements in the tender document concerning the contractor's risk management activities during execution of the contract, Definition of the information requested from the renderers in order to allow an evaluation of the tenderers' ability to manage risk

In order to ensure a basis for comparing and evaluating the tenderers' the tender documents should state the information that each tenderer must present in this respect.

This information should include:

- Information on structured risk management in similar projects and their outcomes
- CV for persons to be responsible for the risk management and details of any specialist organization that has been involved
- General description of the tenderer's intentions regarding his project specific organization and his risk management objectives
- Overview and description of the major risks perceived by the tenderer in the project
- The tenderer's proposed strategy for the management of major risks to the project and how success will be defined and measured.

Requirements concerning the contractor's risk management system should be described. This could include such matters as:

- Organization and qualifications of risk management staff
- Types of risks to be considered and evaluated
- Activities, i.e. description of a minimum requirement of activities to be included in the contractor's risk management,
- Time schedule for risk management activities
- Co-ordination with the owner's risk management, contractors and risk management team
- Control of risks from sub-contractors' activities

5.3.2 Risk management during contract negotiation

Identifying risk issues in the tenders can be used as a basis for tender negotiations. The evaluation of tenders in respect of risk may be qualitative or on a quantitative basis to the extent that the tender price might be adjusted accordingly. The evaluation of the risk issues in the tenders should include [34]:

- An evaluation of the contractor's ability to identify and control risks by the choice and implementation of technical solutions.
- Systematic assessment of the differences in risk between the project proposals by different tenderers;
- Evaluation of the risk management expertise at the contractor's disposal

When a contractor has been chosen, negotiations between the owner and the contractor may lead to a detailed contractual description of the risk management system to be implemented on the project.

5.4 Risk management at the construction phase of tunneling work

The principal contractor and subcontractors have an obligation under the tunneling project to provide and maintain a workplace that is safe and without risks to health for their employees and others in relation to those matters over which they have control.

Control measures to prevent persons being injured during all stages of the tunnel construction and fit out must be provided and maintained as part of a safe system of work [26].

The main activities which should be done accurately during construction phases are;

- selecting Excavation method
- planting equipment
- wearing safety materials
- stand up time and support system
- communication system inside the tunnel work

5.4.1 Ground investigation

A thorough ground investigation could be the difference between success and disaster. Missing fracture zones and areas of weaker rock could cost lots of time and money during the construction [27]. Methods of doing ground investigations include;

- seismic geophysics, rock testing,
- core drilling and
- mapping the area where the tunnel passes through

All these methods help to get a good visualization of what to expect during construction of the tunnel.

5.4.2 Excavation method

The site investigation, including geotechnical investigations and risk assessment, the tunnel design, access limitations and other local factors should be used to establish the appropriate excavation methods. It is usual for a number of different excavation methods to be used on a single project.

The methods of excavation should permit the designed ground support to be installed as planned, and allow for the installation of additional ground support should ground conditions be found to be worse than considered in the design.

Factors to include in determining appropriate excavation methods would include the following [30]:

- the tunnel design, including the dimensions, shape, excavation tolerance of the excavation, and the tunnel support and lining design
- the expertise of the contractors
- available access
- the nature of the ground e.g. reclaimed ground the water table level
- historical excavation experience in the area under similar conditions
- the possibility of flooding from surface run off, tidal water, rivers, dams, reservoirs, lakes or swamps
- leaking storm water drains, water mains or flooded communications conduits
- intersection of old flooded workings or an underground water-bearing structure, such as a fault, cast or perched water table
- the proximity of existing underground services, such as water mains, sewer, drainage, electricity, gas and telephone
- soil nails, rock anchors, basement underpinning, or other pre-existing ground support
- adjacent excavations e.g. shafts, tunnels or trenches
- other hazards, either natural or man-made, such as: heavy loadings, above or adjacent to the tunnel e.g. roadways, railway lines, buildings, rivers or planned or existing spoil stockpiles
- chemical contamination e.g. from past dumping or natural deposits
- the presence of methane, or other hazardous gases e.g. where coal seams are present or vegetation has decayed in the soil
- dynamic loads or ground vibration near an excavation, including: traffic (highway or rail) excavation equipment explosives

Using these criteria the best excavation method for the tunnel work should be determined and the risks that might be happen because of choosing an inappropriate tunneling technique can be reduced.

There are a few things to consider in the planning stages of excavation work. Before excavation work is begun it is necessary to [29]:

- registered as an excavation contractor with the Workplace Safety and Health Division

- notified the Workplace Safety and Health Division of your excavation and obtained a serial number for your excavation
- obtained clearances from underground facilities
- obtained engineering approvals where required
- provided appropriate training for all workers involved in the excavation work

5.4.2 Tunnel entrance protection

Before tunnelling work starts portal entries must be supported by different methods such as; ground support for the high wall above the tunnel entrance.

The tunnel entrance should be also protected from entering vehicles and it should protrudes far enough out from the tunnel to protect people entering or leaving the tunnel from being hit by material falling from the high wall above the entrance, and diverting surface water from the tunnel entrance and providing dewatering resources [29].

To protect entering over height vehicles:

- clearance and advance warnings signs should be installed,
- By installing advance protective barriers and warnings, like 'dangle bars', to warn users that a vehicle will not fit under the structure or tunnel ahead.

5.4.3 Excavation by hand

It is rear to excavate tunnels manually, but different auxiliary works while tunneling could be done by hand. Excavating by hand is generally limited to small sections within larger workplaces like a small shaft, sump or drive-in area with limited access [30].

These risks that commonly associated with excavating by hand can be controlled by the following methods:

- implementing regular face and scaling inspections
- using mechanical lifting gear, winches, rigging systems
- restricting entry to work area
- reducing worker numbers in work place
- monitoring daily exposure limits on vibration
- providing training and information
- supplying lighting and ventilation adequate for the tunnel
- guardrails must be installed at tunnel openings
- toe boards must also be in place to prevent any equipment or debris from falling into the tunnel excavation
- access ways to tunnel excavations must be covered when not in use to prevent falls

5.4.4 Excavation by plant (machine)

The risks which could happen while using machines for excavation of tunnel works can be minimized and controlled using the following methods [30]:

- all cranes or other hoisting equipment must be inspected and maintained according to the manufacturer's specifications, or as required
- providing training to operators and other workers
- supplying lighting, ventilation and communication systems adequate for the task
- setting exclusion zones
- using fire suppression equipment
- using dust suppression sprays, spotters, mirrors, cameras and feelers
- using remote operating or having protective operating cabins
- ensuring plant maintenance and effective traffic control
- having automatic plant cutoff in inflammable atmospheres
- reducing stored inflammable gases

5.4.5 Excavating by TBM

There are different varieties of TBM machines which have different features. The ability to combine features of several types of TBM and other mechanical excavation methods to create hybrid TBMs may eliminate risks but can also introduce new hazards which must be addressed. The risks associated with TBM can be reduced using the following methods [5]:

a. TBM operation failures can be controlled by using lock out systems to prevent accidental starting and auto cut-offs for TBM roll and friction pads on grippers.
b. Access restriction problem can be solved by
    - designing TBMs so there is safe access to maintainable parts including access for screw conveyor wear repair
    - ensuring emergency plans are in place for recovery of injured people
    - planning exit routes
c. chemical exposures can be controlled by limiting underground chemical storage
d. Crush areas around grippers, walking feet or shields can be controlled using monitoring devise, cameras to increase the visual field and by ensuring operators can clearly see when grippers and pads are deployed and if there are any obstructions.
e. Using dust suppression, air filtrations and scrubber units to eliminate ventilation problems.
f. Face collapse including risks from changing ground conditions, mixed face and preferential excavation of soft ground leading to risk of settlement can be controlled by:
    - selecting plant through geotechnical modeling
    - ongoing assessment of ground conditions with geologists and designers during excavation
    - increasing monitoring
    - pre-treating and consolidating ground

- assessing settlement and potential damage

g. Ground support installation including access, ring build, segment handling with cranes, annulus void filling and vibration failures can be controlled by;
   - using remote control bolts
   - correctly operating segment feeder and handling devices including having operators visually check area before use
   - inspecting installed ground support
   - use of exclusion zones so no work is done under unsupported ground

h. Tunnel collapse including ground and rock fall near shields and fingers; lining failure leading to potential ground and rock falls and degradation of excavated ground through drying, flaking and support failure is control by using:
   - using geotechnical assessment during TBM design
   - ongoing assessment of ground conditions and ground support with geologists and designers during excavation
   - using finger shields including hoods
   - mapping ground conditions immediately behind shields
   - designing tunnel lining using geotechnical data and assessment including faults (shearing) and seismic activity including liquefaction
   - having quality assurance programs for lining and annulus void filling

i. Noise exposures can be controlled substituting noise signs by light alarms and audible alarms and by using hearing protections.

j. Water inrush including flooding by using
   - automated or remote operated pumping systems
   - designing the tunnel to prevent flotation
   - calculating pressure for groundwater control
   - monitoring groundwater inflow
   - designing dewatering systems through geotechnical modelling

k. Injuries of workers during TMB operation can be reduced by preventing workers entry to the tunnel below minimum pipe diameter.

l. The TBM design should incorporate the following features in order to minimize the risk associated with it [5].
   - automatic smoke detectors with foam suppression systems and water spray barriers
   - storage facilities for safety equipment like breathing apparatus, self-rescuers, first aid and resuscitation equipment
   - audible and visual pre-start warning systems on major moving parts
   - isolation locks on major moving parts and electrical and pressure systems
   - conveyor belts with pull cords for emergency stop
   - guard rails on moving machinery like conveyor belts and pumps
   - emergency lighting on walkways

- continuous tunnel environmental monitoring giving direct readout to the control cabin with alarms at key locations including above ground
- closed-circuit television in the control cabin with cameras fitted in the areas where spoil is discharged onto the conveyor belts, into the muck skips and in areas where locomotives are moving within the confines of the TBM
- effective communications systems between the control cabin and critical locations
- air-conditioned control cabins
- electrical isolators and lock-off devices fitted on items containing dangerous moving parts
- traffic lights at the rear of the trailing gantry to control the shunting of rolling stock during segment unloading and muck skip filling
- walkways with non-slip surfaces, fitted with handrails with headroom along the entire TBM length
- easy access from one trailer to the next without having to step into the segment unloading area or ring build area
- working platforms in build areas should allow segment erector operators maximum visibility
- lifting devices for segments and other equipment secured against free fall
- back-up power supplies for a main power failure

5.4.6 Excavation by drill and ballast method

Using the drill and blast method for tunnelling work is often limited by environmental constraints characteristic of many tunnel locations. In particular dust, noise and vibration concerns often limit blasting activities in urban locations. Explosives laws require the storage, use and handling of explosives to be licensed. The person conducting a business or undertaking has responsibility for the control, safe and secure storage, use and handling of the explosives.

To minimize the risks associated with drill and blast method the following control measures should be done [5].

- only a competent certificated shot-firer should be allowed by the person conducting a business or undertaking to handle and use explosives
- only enough explosives for immediate use should be transported to the working place (tunnel)
- a blasting plan should be drawn up before blasting is carried out
- explosives should be transported in containers and vehicles specially designed for the purpose
- charging should not start until drilling is completed and electric plant like water pumps are switched off and removed from the area
- in the threat of a thunderstorm, charging with electric detonators should be stopped immediately and the working face evacuated

- using explosive management systems including computer control electronic blasting, blast and initiation design and approval processes
- scaling to minimize risk of rock fall
- drilling of lifter holes first where necessary
- vibration monitoring
- smooth blasting
- providing a coating of shotcrete, known as a ’flash coat’, for immediate ground support
- controlling blasting fumes and dust using dust suppression sprays
- avoiding face instability using split face excavation - heading and bench
- using hearing protection materials
- arranging the charging and explosion time should be in the absence of workers

5.4.7 Settlement and deformation monitoring

Real time deformation monitoring allows for the continuous assessment of the potential risk. The underground construction work imposes to the existing infrastructure, and enables the contractor to make adjustments to the construction practice should intolerable risk situations arise.

To control risks of deformation and settlement during tunneling the following measures should be taken [27];

- When possible, use automated surveys with high frequency measurements to capture settlement trends, precisions, systematic shifts, etc.
- Deploy a high density array of monitoring points to determine the zone of influence due to tunneling.
- Obtain as much baseline data as possible to identify potential issues with the measurements such as drift, poor line of sight, natural oscillations in ground deformation and seasonal effects.
- Independently verify measurements using other remote sensing techniques (e.g. Lidar, InSAR, etc).
- When site conditions prohibit automated and continuous surveys, extensive measures should be taken to maintain good control when conducting manual survey measurements (e.g. multiple control points, higher frequency measurements, well-protected stakes and markers).

5.4.8 Providing tunnel support system

Most tunnels need permanent ground support. The permanent lining can be installed as the excavation progresses or temporary support installed followed by a permanent lining. A second lining may also be installed.

Control measures should be implemented to avoid ground or materials like shotcrete falling on people. Risks from falling objects should be minimized, so far as is reasonably practicable, by providing effective barricading to stop people from accessing high risk areas. The potential for serious injuries from falling shotcrete is equal to those from falling rock [5].

- The ground conditions should be inspected in line with the inspection plan as the excavation progresses.
- Providing a coating of shotcrete, known as a 'flash coat', for immediate ground support
- Undertaking wet drilling of holes for dust suppression
- daily checks of the condition of drill sets and tools and carrying out relevant maintenance
- using procedures for flushing holes with water or air including keeping hands and face clear of pressurized water and air
- Correct procedure and supporting technique must be used in order to prevent rock falls or tunnel collapse when installing ground support.

1. Shotcreting

During shotcreting process different risks can be faced and to prevent those hazards the following activities should be done [30].

- Shotcrete mixture should be designed to meet the strength and workability specified and to minimize dust levels.
- Surfaces contaminated with oil, dust or mud should be cleaned before shotcrete application and water entry is diverted.
- During shotcreting no other activities should be carried out.
- Providing exclusion zones and traffic management planning, lighting on the plant and at the work face and plant reversing alarms during transporting concrete.
- using suitable personal protective equipment's including impact-resistant goggles, helmet, gloves, breathing apparatus, hearing protection, safety boots and full body clothing
- regular servicing of the plant according to the maintenance plan
- training the plant operators and workers
- ensuring no entry to unprotected, unstabilized freshly sprayed areas

2. Rock bolting

To minimize the risk during rock bolting

- Using appropriate technique or equipment for fixing the bolt
- The holes for bolts should be through the lattice girder in order to reduce the over breaks
- Grouting the rock bolt after installation in order to increase the strength

3. Segment lining

The installation of segments should be only after reaching the requirement its strength.

To prevent the damages during installation or after construction [23]:

- Before installation the segment should be inspected for damages
- Applying correct procedure during erection of the segment
- The operator of the erector must be experienced
- Minor concrete flaking due to compression during the ring installation cannot be prevented so surface concrete repair is necessary
- The ring grouting has large influence on the segment behavior so by controlling the grouting the damage of the segment can be avoided

4. Installing steel ribs and steel girders

During the installation of the girder support the following activities should be done to minimize the risk from happening [23].

- Properly scaling of the under breaks and loosen rock blocks
- Shotcreting and making the surface secure
- Installing the steel girder should be checked by laser guidance system or surveyor
- The girder should be fastened properly
- The final shotcrete should be enough to fix the steel girder

5. Ground freezing

Cold effect and freezing can be minimize by using equipment adapted for cold operation, cold protecting equipments and by scheduling job rotation and rest periods. It is also possible to control the specific risks by monitoring [23]:

- temperature and refrigeration plant
- ground movements and
- oxygen levels

6. Pipe jacking

Some of the control measures which should be implemented to eliminate or minimize the risks associated with pipe jacking is [37]:

- Jacking operation should be mechanical rather than manual
- Providing support during jacking to prevent soft ground tunnel face from collapse.
- dewatering or grouting to reduce water inflow
- provide lighting system during jacking
- preventing or do not allow peoples from entering during the pipe jacking

7. Compressed air support

The risk of fire is higher than in normal tunnel operations from the increased oxygen present in the compressed air. Therefore Fixing fire extinguishing systems should be an integral part of tunnelling equipment when using compressed air. To eliminate the risk caused by compressed air tunneling [23];

- installing fire extinguishing system
- implementing emergency rescue procedures
- ensuring constant air flow to provide ventilation and temperature control
- providing fully manned medical airlock on site during compressed air tunnelling work
- providing emergency rescue team

8. Pressure grouting

Risks can occur to the workers during pressure grouting, so it is necessary to control it by implementing rules such as [37]:

- providing easy to read pressure gauge to assist in reducing the risk of exceeding specified grout pressure
- documenting the grout plan listing specified grout pressures and patterns
- limiting hose lengths to minimize tripping hazards

- using pressure release valves
- using personal protective equipment like gloves, dust masks and full face eye shields

9. Tunneling ventilation system

The workplace must be ventilated to enable workers to carry out work without risk to health and safety. The consequence of poor ventilation system causes; excessive heat, oxygen depletion and fumes and substances that could lead to health problem even death. So to get the workplace with good air quality [5, 6]:

- The quantity of air supplied or extracted from the face should be so the average air velocity at a full cross section of the tunnel or shaft is between 0.3 m/s and 2 m/s at all times.
- The minimum quantity of air for people should be 1.5 m_3 per minute per worker and 4 m_3 per minute per kW of rated diesel power.
- Workers in areas with a wet globe bulb temperature in excess of 27 ° C should be provided.

To control the air inside the tunnel different ventilation methods should be apply.

Mechanical ventilation is one way to [5, 6]:

- ensure oxygen is available for respiration from fresh air
- dilute and transport harmful atmospheric contaminants away from work areas
- have enough air flow to eliminate or minimize contaminants, so far as is reasonably practicable, and
- Provide cooling for people working in warm and humid environments.

10 .Environmental contamination

Due to the nature of tunnelling work, contaminants generated in one area of the tunnel will move readily to other areas. Protection against airborne hazards should be provided to workers. Possible sources of the generation of dust(hazardous chemicals) in a tunnel should be identified and control measures implemented to eliminate or minimize, so far as is reasonably practicable, the generation of the dust at the source. To minimize the environmental contamination from the tunneling work [30];

- Storing materials on the surface in places away from where ventilation fresh air intakes could be compromised through a surface fire or chemical spill.
- Providing re-entry testing procedures including re-entry times after blasting explosives.
- providing personal or machine-mounted continuous monitoring devices that sound an alarm when dangerous gas levels are reached
- monitoring air flows for explosive gases and atmosphere contaminants regularly
- using wet spraying to suppress dust at the point of generation
- using extractors or dust collection devices in-line near the face
- maintaining extraction at or close to the point of generation by using brattice curtains or half-curtains to reduce dust roll-back

- Using technology the hazardous dusts and chemicals should treat before exposed to the environment.

5.5 Risk management during service time of the tunnel

During the service time of the tunnel different risks can happen by many factors such as; traffic collision, absence of ventilation and light, absence of ground monitoring system, lack of technology, earth quake and fire accidents. In order to get the required service of the tunnel, risks which can face at the operation phase of the tunnel should be reduced by different controlling measures. Planning and developing those controlling measures are duties of both contractors and client.

5.5.1 Controlling traffic flow

The traffic around and within the tunnels is both monitored and controlled by the Traffic Monitoring and Control System, with the traffic information presented on a graphic screen. The TMCS monitors the current traffic sign through the outstation PLC and the CCTV system. These include the VMS at tunnel portal, and lane control signs located above each traffic lane. Based on the incident and status from the AIDS, the TCS & VMS can be directly controlled by the operator or SCADA system to close a lane or give early warning of queues forming ahead. The Traffic control system also provides a series of pre-defined traffic plans which selectable by operators during emergency situation such as fire alarm or accident in the tunnel [17].

To help manage traffic control, and to endorse traffic safety, certain measures are applied, including [17]: road signs

- guiding equipment, such as, floor labeling and side reflectors
- height control, responding to oversized vehicles
- alarm sensors to notify drivers of emergencies before entering the tunnel
- video monitoring high density tunnels or tunnels longer that 1,500 m
- speed sensors, to encourage users to respect the speed limit

5.5.2 Providing telecommunication

Most tunnels are equipped with communication devices that will allow users to communicate with the authority for health and safety hazardous in the likely event of an emergency. These are normally provided for tunnels greater than 500 m long, and are spaced out through the entire tunnel with a fixed distance (150 m) [17].

5.5.2 Providing signals

After sinking operations have been completed and before tunneling operations are begun from any shaft, there shall be provided and maintained two separate systems of signaling, which shall be either electrical, pneumatic, or mechanical, or one such system supplemented by a speaking tube or telephone [19].

5.5.3 Providing ventilation and light system

Ventilation is important in order to maintain a habitable environment, it is important to note that there are different requirements for ventilation during construction (i.e. tunnel heading), and service ventilation during regular use.

For the same reason as during construction, ventilation is necessary in order to reduce the concentration of polluted air. It is also an important factor to secure visibility and direct a single directional flow in the event of a fire. The amount of fresh air needed should be calculated with respect to tunnel dimension and estimated daily traffic volume [17].

As a safety measure and a convenience towards end user, tunnels are illuminated to ease the transition from the natural light on open roads relative to that in tunnels. The philosophy in tunnel illumination is to provide sufficient lighting to reduce the risk of accidents, while also reducing the amount of electricity needed to maintain a functional tunnel.

5.5.4 Settlement and deformation monitoring

Deformation monitoring should be also at its service because deformation monitoring allows for the continuous assessment of the potential risk the underground construction work imposes to the existing infrastructure, and enables the contractor to make maintenance work or other remedial measures to keep its service.

To reduce deformation and settlement of tunnels the following measures should be taken [5];

- When possible, use automated surveys with high frequency measurements to capture settlement trends, precisions, systematic shifts, etc.
- Obtain as much baseline data as possible to identify potential issues with the measurements such as drift, poor line of sight, natural oscillations in ground deformation and seasonal effects.
- Independently verify measurements using other remote sensing techniques (e.g. Lidar, InSAR, etc).
- When site conditions prohibit automated and continuous surveys, extensive measures should be taken to maintain good control when conducting manual survey measurements (e.g. multiple control points, higher frequency measurements, well-protected stakes and markers).

5.5.5 Installing the drainage system

There are three main sources of water that need to be diverted from the tunnel, ground water, service water (e.g. tunnel washing) and day water (e.g. rainwater or melting ice entering the portals). Due to this, tunnels are constructed with a certain incline, for underwater tunnels, the lowest longitudinal point will be located near the middle of the tunnel, in which case pumps are necessary to divert water and prevent flooding.

Drains, collecting pipes and other pipes must be laid in separately blasted pipe trench along the wall of the tunnel. Drain Pipes should be connected to collecting pipes (surface water pipes) by means of gullies. In order to dewatering the surface water gullies should be installed in tunnels and connected to the longitudinal pipes [19].

5.5.6 Fire protection

Fire hazard is considered to be more dangerous in the confined space of a tunnel, for this reason it is very important to take precautionary steps to guard in the likelihood of a disaster. The result of a fire may also damage the concrete walls, as water entrapped in the pores of the concrete transform into vapor, increasing pressure and causing flakes of concrete to fall off. Besides this, thermal expansion is also an issue that needs to be addressed [17]. There are methods to increase the fire resistance of concrete, such as avoiding minerals that disintegrate at higher temperatures. This can be broken down into three categories:

- Precautionary measures (fire resistant construction material, escape routes, etc.)
- Cautionary measures (heat, gas, smoke, flame detectors)
- Active mitigation (fire extinguisher, fire blanket, fire hose)

Along with fire protective construction material, safety monitors such as heat, gas, smoke and flame sensors can be used.

5.6 Summary on the control measures

When this chapter is summarized; to control the risks associated with tunnel construction the following main activities should be done.

- developing risk management policy, safety and strategy plans
- proper design of the support type and site investigation
- estimating the accurate average standup time
- selecting construction method and technologies
- implementing the proper installation of support type
- training the employee and hiring experienced technicians
- identifying the risk factors, and its impact the tunnel project
- developing risk response method
- monitoring and controlling the construction of the tunnel
- using personal protective equipment
- providing different signals and clearance and advance warnings signs should be installed,
- by installing advance protective barriers and warnings

5.7 Adopted risk remedial measures

According to the lessons learned from different tunnel construction failures, and from the questioner survey gained, the remedial measures which are commonly used by the stake holders involved in tunnel construction are;

- redesigning the tunnel support system
- re estimating the correct average stand uptime
- mucking out the collapsed masses
- quickly repairing by providing the tunnel supports
- installing/using more powerful excavation equipment
- use abundant ventilation and fire protection
- constant monitoring and controlling deformation and settlement of the tunnel
- changing the alignment of the tunnel
- construction of a new exploratory Adit on the other side of the tunnel
- repairing the drainage holes, and drainage pipes systems
- using water proof material and by properly grouting to prevent the water inrush into the tunnel surface
- using high expansion polymer resins that support the void to prevent further material falling

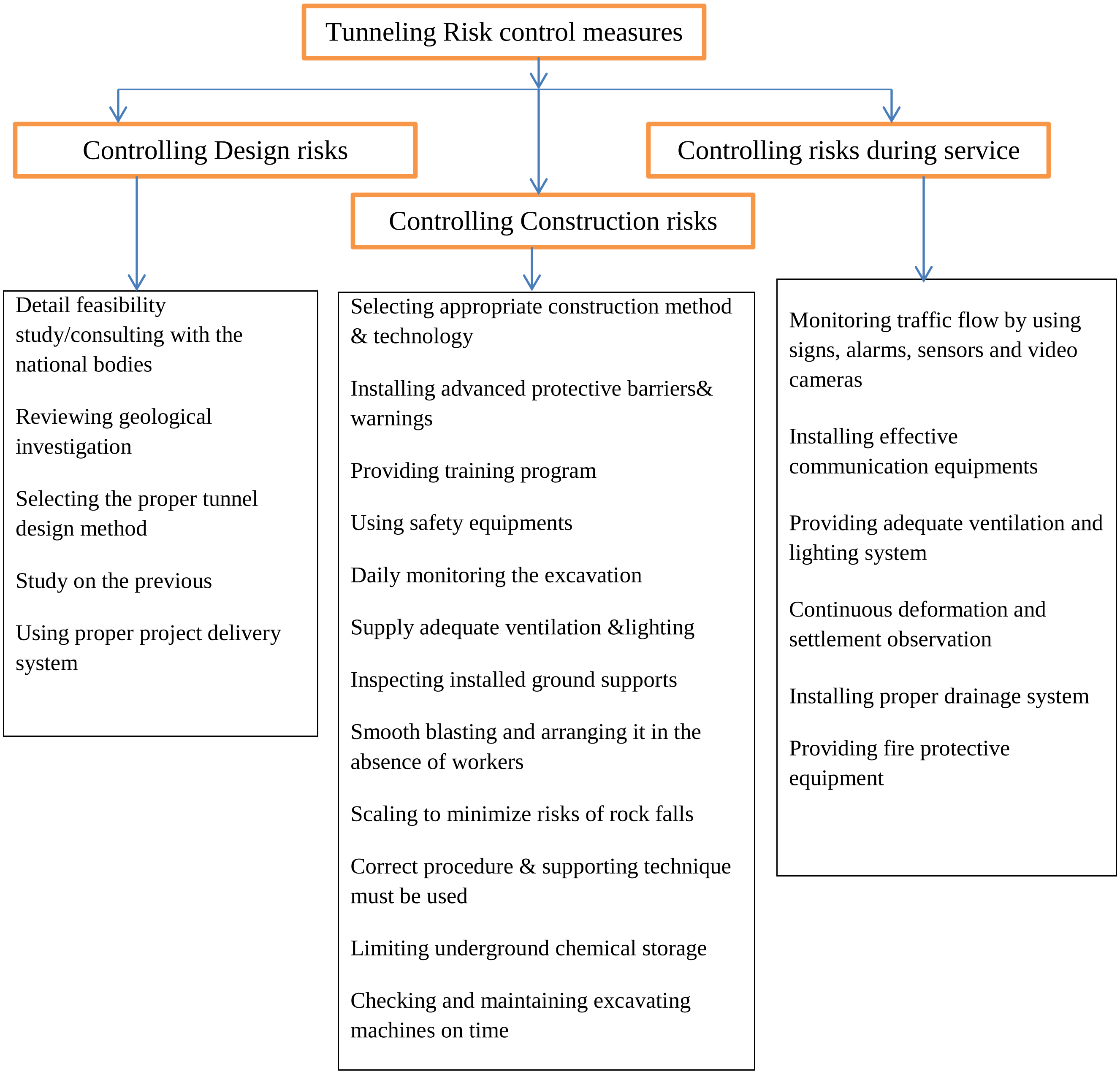

Figure 24 Tunneling risk controlling measures

5.8 Adopted guideline for tunneling construction

To mitigate risks associated with tunneling selecting appropriate construction technique and excavation equipment depending on the ground investigation and tunnel type. This guideline is then indicates which type of technique is acceptable to use other wise to avoid it depending on different factors like length, diameter and ground condition. This guide is developed based on past and current tunnel practices information [22, 24].

Table 18 Tunnel excavation techniques and its length

Excavation technique	L(km)	<0.3Km	0.5Km	1.0Km	>1.5Km
manual		acceptable	Avoid	Not acceptable	
Plant/mechanical		acceptable			avoid
TBM		avoid	acceptable		
drill & blast		avoid	acceptable		

Table 19 Tunnel excavation techniques and its diameter

Excavation technique	D(m)	<1.5m	3m	7m	>9m
manual		Avoid	Not acceptable		
Plant/mechanical		acceptable			avoid
TBM		Not acceptable		acceptable	Not acceptable
drill & blast		avoid	acceptable		

Table 20 Tunnel excavation techniques and the ground condition

Excavation technique	Soft ground	Varity ground	Hard rock
manual	avoid	Not acceptable	
Plant/ mechanical	acceptable		avoid
TBM	acceptable		avoid
Drill & blast	avoid	acceptable	

Notes

1) this guidance should be read with conjunction to the chapter five
2) this guidance is developed based on reviewing related studies and current tunneling in Ethiopia
3) All manual excavation are categorized as ''not acceptable'' or ''avoid'' that is due to the unforeseeable underground risks, unsafe access and inadequate working space etc.
4) the designer should compile the three table while using in order to minimize the risks during tunneling

Definitions

Acceptable –designers should undertake an assessment on the excavation technique and on the associated risk and specify the appropriate mitigation measures

Avoid –designers should undertake risk assessment to justify their decision from acceptable criteria. Contractors being asked to construct using this category should also seek advice from the planning supervisor/ coordinator on the adequacy of their risk mitigation measures.

Not acceptable-the designer should specify another alternative tunneling technique

5.9 Risks category during tunneling phase

Risk assessment should follow the construction process. Each phase of the project has a goal that must be achieved. The goal of each tunneling phase depends on some activities that affect the phase realization. These activities are potential sources of risk and a cyclical risk assessment should be repeated for each phase of the project. It is necessary to take into account that executing tunneling project is a process, and that risk management must follow that process.

Then for this research the risks at different phase of the tunneling are described and summarized in percentage; and this is done based on the data collected from the tunnel experts and by making an analysis, risks associated with tunneling are summarized in table as shown below.

From the table we see that risks can occurred in the three phase of tunneling and we can observe that those risks occurring during construction phase takes the largest percentage. This indicates that most risks are associated with construction phase of the tunnel. Risks associated with design and operation holds the smaller percentage.

Table 21 risks associated with tunneling phases

Tunneling phase	Risk catagory	Percentage	Total percentage
Planning & Design risks	1. Design errors and omissions	2%	25%
	2. Design process takes longer than anticipated	4%	
	3. Stakeholders request late changes	2%	
	4.Failure to carry out the works in accordance with the design contract	3%	
	5. contractor delays,	4%	
	6. Scheduling errors	4%	
	7. Environmental analysis incomplete	3%	
	8. improper/unfair /delay in resettlement of the land owners	3%	
Construction risks	1.collapses of tunnel section	4%	55%
	2. construction equipment failure	8%	
	3. Falling of excavated soil & rocks	4%	
	4. changing conditions – strata and stress field	8%	
	5. tunnel instability – rock or earth falls and rock bursts	7%	
	6. high noise levels and vibration and dust	4%	
	7. excessive seepage and ground water inflow	6%	
	8. fire or explosion problem	3%	
	9. Inexperienced workforce and staff turnover	8%	
	10. construction cost increasing	5%	
Operation and maintenance risks	1.air contamination or oxygen depletion	2%	20%
	2. Public objections/challenges	3%	
	3.Laws and local standards change	2%	
	4.fire or explosion problem	5%	
	5.lack of monitoring	3%	
	6.settlment problem	3%	
	7.lighting & communication problem	2%	

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The study indicates that most challenges and tunneling risks are occurring during excavation phase, this is due to the uncertainty of the ground and fluctuation of the stress and deformation of the ground condition. Selecting the appropriate excavation method, technology and continuous monitoring are best risk controlling measures. As we can see from the tunnel construction in our country the railway tunnels are constructed by conventional method/NATM/ which is the accurate method to control the weak zones during excavating the surface. Due to these risks were controlled in most railway tunnels in Ethiopia, but hydropower tunnels like Gilgel Gibe II, III, Beles hydropower had faced risks which caused loss of life and damage to infrastructure that is because of the inaccurate estimation of average stand uptime, and construction method they were used. The other main important thing is clear and detail ground investigation makes easiest in selecting the type of construction method and supporting type, which help to reduce the tunnel failures.

To manage the risk of tunnel construction effectively and efficiently, the contractor should have a guideline for risk management of tunnel construction and he must understand risk responsibility, risk even condition, risk preference and risk management capabilities. This study shows that having well organized safety departments like that Awash-Weldia- Mekelle railway projects; risks are reduced as the required level. Most of these companies have clearly registered risk assessment plan and management policies, which helps them to control risks. Based on the qualitative risk analysis procedure, risks are identified and risk matrix is developed for the Awash- Weldia- Mekelle railway tunnels. The risk matrix result indicates that most of the risks associated during construction phase of the tunnel are categorized into high risk level while most of risks are assigned in the medium level and other external risks are grouped the low risk level. Therefore the high risk level must be reduced to the acceptable level or different risk mitigation measures must be developed in order to control the risk impact on the project goals.

As the study indicates that, the choosing of the alternative risk response method is quite different for each tunneling work challenges, but while selecting the risk response method it is necessary to consider the project Scope and goal. Based on the level of risk, risk response is a key component for risk management in tunnel construction, which involves choosing the appropriate control measures to eliminate or reduce the chance of occurring or consequence of the risk.

Finally the study adopted risk management guideline to make the risk management easy and to create safe working condition during the tunnel construction phase and helps for those who participate in the tunnel construction.

6.2 Recommendations

Even though tunneling risks are complex in nature it is necessary to manage (control) it in different means before happening or after occurring, and it should be in systematic way of risk management process that is developing guideline in order to manage risks effectively, this is the importance of this paper. Qualitative risk analysis is general way of assessing risks but high level risks should be analyzed by quantitative risk analysis method and it is better to develop risk analysis models to manage risks in good manner.

For safe and successful tunneling project, it is recommended to fulfilling the following activities;

- properly understand the project scope and objective
- detail site investigation and environmental analysis
- accurate support type estimation and design, based on the average stand uptime of the surface
- selecting appropriate construction/ excavation technique
- developing risk policy, the identified risk should be registered ,and should be updated by the responsible body
- risk mitigation measures should be described or listed accordingly
- the project manager should make the project working condition safe and daily reports should be managed properly
- nothing is more than life, so the projects must be built to serve for people not to harm living thing or the environment

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Glossary

Contractor the organization appointed by the client for the implementation for the tunnel work, appropriate to the form of contract
Code is the code of practice for risk management of tunnel works.
Client the final owner of the tunnel works and the procurer of goods or services
Construction stage the stage of tunnel works project that involves all aspects relating to the implementation of designs for the completion of the work to the requirement of the client.
Design stage the stage of tunnel works project which involves the preparation of preliminary and detailed designs for permanent tunnel works and temporary works designs during the construction stage.
Excavation means a dug out area of ground and includes a deep foundation excavation, trench, tunnel and shaft.
Hazard – An event which has the potential to impact on matters relating to a project which could give rise to undesirable consequences.
Key personnel a named staff identified by an organization that is nominated to undertake important roles within the work scope required.
Lining is the necessary permanent ground support system to the periphery of a tunnel or shaft excavation, and/or the material installed in the same position with an inner surface suitable for the specific end-use of the underground excavation
Mucking is the action of removing excavated mass from the advance section.
Open excavation means an excavation in which the width is greater than the depth, measured at the bottom.
Project development stage the stage of a tunnel works project which includes project feasibility study, site investigation and the assessment and evaluation of project options including identification of a preferred project option and form of contract for construction.
Risk means a combination of the probability of an event occurring and its consequence for project objectives.
Risk management is the process of identifying, analyzing, assessing and controlling risks on a project.
Risk register is a formalizes record of risks identified from the risk assessment process including full descriptive details of mitigation and control measures, risk owners and with appropriate cross references.
Support structure means a temporary or permanent structure or device designed to provide protection to workers in an excavation, tunnel or shaft from cave-ins, collapse, sliding or rolling materials
Tunnel means a generally horizontal excavation that is more than a meter long and located underground.
Tunnel Risk Assessment – The process of identifying geotechnical hazards and risks, evaluating their potential consequences and likelihood of occurrence, together with strategies for preventative and contingent action.
Tunnel Risk Management – The overall systematic process of tunneling risk assessment, and risk mitigation and control.
Tender documentation is documentation prepared and issued by a client when the service or goods of a supplier that detail the services or goods required and issued.
Trench means an excavation that is deeper than its width measured at the bottom.
Third party a party that is affected by the action of other parties that is in a contractual relationship.

Appendices

Appendices A) the prepared questionnaire sample

1. Name ……………………………………………………………………………………………………….
2. Your Work position………………………………………………………………………………………….
3. Project name which you are participating……………………………………………………………….
4. Purpose of the tunnel project you have been participating

   Railway tunnel ☐ hydropower tunnel ☐ highway tunnel ☐ another ☐

5. Fill the tunnel properties you have been working on

Tunnel of properties	
Length of the tunnel(km)	
Shape of the tunnel	
Diameter(m)	
Method of construction	
Support type	
Geological condition of the tunnel	

Table1 Tunnel general information

6. Are there any challenges during the construction?

   Yes ☐ No ☐

7. If yes what kind of challenges did you faces?
   - Design challenges ☐
   - Nature of the ground ☐
   - Skill and experience of man power ☐
   - Type of technology used ☐
   - Environmental weather ☐
   - Economical factor ☐
   - Social relationships ☐
   - If any other challenges mention it …………………………………….
8. Are there any failures during the construction?

   Yes ☐ No ☐

9. If any which type of collapse?
   - cave-ins or excavation collapses
   - Falling of rock materials
   - Explosion mixture of air and gas
   - Shortening of tunnel diameter
   - slips, trips, and falls of earth material
   - hazardous atmospheres
   - flooding/water hazards

10. What were the causes for the failures?
    - Uncertainty of the ground
    - Earthquake
    - Explosive mixture of air and gas
    - Pumping action of water
    - Method of excavation
    - Type of equipment and experience of working
    - Inherent spatial and temporal variability;
    - Measurement errors (systematic or random);
    - Model uncertainty;
    - Load uncertainty; and Omissions
    - If any other cause ……………………………….
11. What was the consequence of these risks?
    - High financial losses
    - Unsafe working condition
    - Damage to working machineries and infrastructure losses
    - Death , injuries or Health problem to workers
    - Delay the construction time
12. What kind of remedial measures had taken to overcome these failures?
    - Redesigning the tunnel support
    - Estimating the correct average stand uptime
    - Quickly repairing the tunnel using supports
    - Use abundant ventilation and fire protection
    - Constant monitoring and controlling deformation and settlement of the tunnel
    - Changing the alignment of the tunnel
13. Give your rank for the mentioned risks below which could happen during tunneling

categories	Likelihood 1(rare)-5(frequently)	Impact 1(very low)- 5(very high)
Design risks		
1. Design errors and omissions		
2. Design process takes longer than anticipated		
3. Stakeholders request late changes		
4. Failure to carry out the works in accordance with the contract		
External risks		
1. New stakeholders emerge and request changes		
2. Public objections		
3. Laws and local standards change		
4. Tax change		
5. construction cost increasing		

Environmental risks		
1. Environmental analysis incomplete		
2. air contamination or oxygen depletion		
Organizational risks		
1. Inexperienced workforce and staff turnover		
2. Delayed deliveries		
3. Lack of protection on a construction site		
Project management risks		
1. Failure to comply with contractual quality Requirements		
2. Scheduling errors, contractor delays		
3. Project team conflicts		
Right of way risks		
1. Expired temporary construction permits		
2. Contradictions in the construction documents		
Construction risks		
1. cave-ins or excavation collapses		
2. construction equipment failures		
3. Falling of excavated material		
4. changing conditions – strata and stress field fluctuations		
5. tunnel instability – rock or earth falls and rock bursts		
6. high noise levels and vibration		
7. excessive seepage and ground water inflow		
8. fire or explosion problem		

Table 2 Risk categories and risk assessment

14. From the listed below control measures which do you prefer in order to manage the risk during tunneling? Mention if any other.
    - Identifying the risk factors and risk response method
    - Developing risk management policy, safety and strategy plans
    - Proper design of the support type and site investigation
    - selecting construction method and technologies
    - Training the employee and hiring experienced technicians
    - monitoring and controlling the construction of the tunnel
    - ……………………………………………………………………………………………
15. Which risk response method do you suggest

Risk type	Alternative Risk response methods									
	R_t	R_{d1}	R_{d2}	R_{d3}	R_{d4}	T_1	T_2	E	C	N
1. Design errors and omissions										
2. Design process takes longer than anticipated										
3. Stakeholders request late changes										
4. Failure to carry out the works in accordance with the contract										
5. New stakeholders emerge and request changes										
6. Public objections										
7. Laws and local standards change										
8. Tax change										
9. construction cost increasing										
10. Environmental analysis incomplete										
11. air contamination or oxygen depletion										
12. Inexperienced workforce and staff turnover										
13. Delayed deliveries										
14. Lack of protection on a construction site										
15. Failure to comply with contractual quality Requirements										
16. Scheduling errors, contractor delays										
17. Project team conflicts										
18. Expired temporary construction permits										
19. Contradictions in the construction documents										
20. cave-ins or excavation collapses										
21. construction equipment failures										
22. Falling of excavated material										
23. changing conditions – strata and stress field fluctuations										
24. tunnel instability – rock or earth falls and rock bursts										
25. high noise levels and vibration										
26. excessive seepage and ground water inflow										
27. fire or explosion problem										

Table 3 Alternative risk response methods

Note: **Risk response methods**

R_t: Risk retention
R_{d1}: Risk reduction by addition information acquisition
R_{d2}: Risk reduction by physical protection
R_{d3}: Risk reduction by personnel management
R_{d4}: Risk reduction by work adjustment
T_1: Risk transfer by subcontracting
T_2: Risk transfer by construction insurance
E: Risk elimination (avoidance)
C: Contingency allowance
N: Risk not considered by Contractor

16. Do you know any other way of managing risks which happened during tunneling project?

    ………

    ……..

17. If you have any comment or advise which I didn't included in my questioner?

    ………..

    ……

Appendix B;

1. sample of risk assessment method developed by AKP railway project team

ERC **AKH Railway Project** yapı merkezi

No.	Faaliyet/ Hizmet Activity / Service	Çevre Boyutu Env. Aspect	Normal, Abnormal Acil / Emergency	Sınır (%40) Consequence Level	Olasılık (%30) Likelihod	Miktar ve Süre (%30) Dose	Etki Impact	Öncelik Priority	Planlanan Kontrol Faaliyetleri, Planned Management & Monitoring Actions	Çevre Amaç ve Hedefi Environmental Objective and Target	Sorumlu(lar) Responsible(s)	Kaynaklar ve bütçe Sources and Budget	Sonuçlar /Durum Değerlendirme Results / Status Review
	Construction Works Civil Structure Tunnels	Hazardous and non-hazardous wastes	Normal	2	4	3	2,9	2	Different streams of hazardous wastes shall be segregated. Chemical wastes shall be clearly labeled in English/Turkish /Amharic; shall be stored in corrosion resistant containers and arranged so that incompatible materials are adequately separated. Chemical wastes generated on-site will be recycled where possible. Segregated storage shall be provided and local authority approved disposal for non-hazardous wastes (i.e. packaging material, empty containers, canteen/office wastes, sewage sludge).	Our aim is to reduce, mitigate or prevent contamination of land, water and pollution of air where possible with the Best Available techniques. Our target is reuse and recycle our construction remainings at most, manage all the hazardous waste and zero waste from refectories	Tunnel Works Dept.		

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2. tunneling inspection method

ERC SYSTRA MD **AKH Railway Project** yapı merkezi

SUMMARY OF CONSTRUCTION INSPECTION AND TEST PLAN

Location:	Awash-Kombolcha-Hara Gebaya Project													
Field:	Civil-Works													
Specialty:	Tunnel Construction Section from km… to km …										Type of Record		Supervisor Signature	
ACTIVITY	ITP NO.	form	WORK ITEM OR VERIFICATION SHEET TITLE	Tunnel	Cross-passage	Ventilation Shaft	Laboratory			Remarks	Report	Verification Sheet	Yes	No
EXCAVATION WORKS	001	a	Geodetic setting out							drawings of axes,levels and coordinates of the tunnel section		x	x	
		b	Exacavation works							excavation report sheet		x	x	
		c	Topograph measurement							topo final excavation sheet		x	x	
STEEL REINFORCEMENT	2	a	Identification of the steel frame (type, correct orientation, proper insertion)							steel latice girder assembly act		x	x	
		b	Identification of the steel mesh (type, correct orientation, proper insertion)							certificates and declaration of conformity		x	x	
		c	Identification of the rock bolt (type, correct orientation, proper insertion)							certificates and declaration of conformity				
		d	Control of quality of materials used							certificates and declaration of conformity		x	x	
		e	Checking of the spacers between two frames							observation control				x
CONCRETE WORKS	003	a	Topograph measurement	x						topo before concrete sheet		x	x	
		b	Average rate of concrete	x						concrete report		x	x	
		c	Number of trucks,time arrival,volume and consistency test	x						concrete truck report		x	x	
		d	Strenght test 3-rd day				X			compressive strenght test,mix design		x	x	
		e	Strenght test 7-th day				X			compressive strenght test,mix design		x	x	
		f	Strenght test 28-th day				X			compressive strenght test,mix design		x	x	
		g	Control of quality of materials				X			certificates and declaration of conformit		x	x	
		h	Mix design of concrete formula							mix design report		x		x

SUMMARY OF CONSTRUCTION INSPECTION AND TEST PLAN	AKH-YMI-AL-TU00X-I-GT-ITP-0001-0	06.06.2015
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3. tunnel excavation and support daily report format

ERC SYSTRA MD AKH Railway Project yapı merkezi

Tunnel Daily Face Excavation & Support Report

LOCATION / YERİ	:					WEATHER CONDITIONS:		DATE :
TUNNEL FACE /AYNA	:					TEMPERATURE :		TARİH :
DRAWING	:	Chainage Start :	Top Heading km:	Bench km:	Invert km:	PRECIPITATION :		SIRA NO :
SPECIFICATION	:	Chainage End	Top Heading km:	Bench km:	Invert km:	WIND :		RECORD NO

	Production / Hour:	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00
TOPHEADING	Umbrella&Forepoling Drilling																								
	Umbrella&Forepoling Installing																								
	Excavation																								
	Mucking																								
	Preliminary (Protection) Shotcrete																								
	1st Layer Wire Mesh																								
	Lattice Girder Installation																								
	2nd Layer Wire Mesh Installation																								
	2nd Layer Shotcrete																								
	Rock Bolt Drilling																								
	Grouting																								
	Other Works																								
	Stand By																								
BENCH	Excavation																								
	Mucking																								
	1st Layer Wire Mesh																								
	Lattice Girder Installation																								
	1st Layer Shotcrete																								
	2nd Layer Wire Mesh Installation																								
	2nd Layer Shotcrete																								
	Rock Bolt Drilling																								
	Grouting																								
	Other Works																								
	Stand By																								
INVERT	Excavation																								
	Mucking																								
	2 Layer Wire Mesh																								
	Shotcrete																								
	Other Works																								
	Stand By																								

Umbrella / Forepiling /Face Nailing (Drilled & Grouted)			Excavation	Chainage-km		D. Progres	Lattice Girder Installation				Shotcrete	Chainage-km		Volume	Rock Bolt (Drill&Grout)	Chainage-km		Leng	Nos
Location /Yeri	Description	Nos	Section	From	To	(m)	Section	No	Section	Location	Section	From	To	(m3)	Section	From	To	m	pcs
			Top Heading				Top Heading				Top Heading				Top Heading				
			Bench				Bench				Bench				Bench				
			Invert-Rigth				Invert-Rigth				Invert-Rigth								
			Invert-Left				Invert-Left				Invert-Left								

Machinery&Equipment	Model/Type	C	SC	Start	End	Staff Nos	DAY	NIGTH	Rock Bolt (Torqued)	Chainage-km		Description	Notes
Jumbo									Section	From	To		
Umbrella Arch Driller									Top Heading				
Excavator									Bench				
Loader									Invert-Rigth				
Shotcrete Pump									Invert-Left				
Manlift													
Dump Truck													
Transmixer													
Compressor													
Generator													
Ventilator													

	YAPI MERKEZI	EMPLOYER'S REPRESENTATIVE
Name / İsim		
Signature / İmza		
Date / Tarih		

Tunnel Daily Face Excavation & Support Report	AKH-YMI-AL-TU00X-I-GT-FRM-0001-0	08.06.2015
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