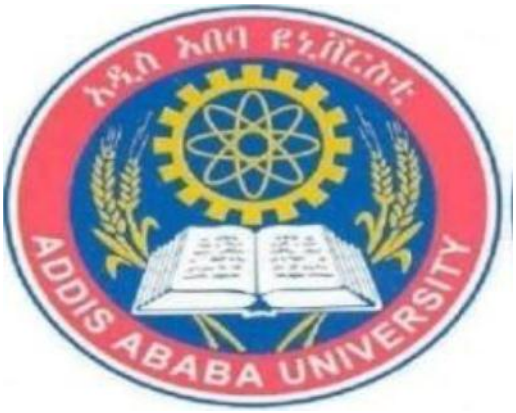
ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY



Assessment of Potential Causes of Construction Delay in Tunnels; A Case Study at Awash-Weldiya Railway project

By: Shambel Meressa

Advisor: Girmay Kahssay (Dr.)

A Thesis submitted to the school of Civil and Environmental Engineering

Presented in Partial fulfillment of the requirements for degree of Master of Science (Railway Civil Engineering)

Addis Ababa University

Addis Ababa, Ethiopia

October 2017

Assessment of Potential Causes of Construction Delay in Tunnels; A Case Study at Awash-Weldiya Railway project

Shambel Meressa

A Thesis Submitted to

The School of Civil and Environmental Engineering

Presented in Partial Fulfilment of the Requirements for the Degree of Master of Science

(Railway Civil Engineering)

Addis Ababa University

Addis Ababa, Ethiopia

October 2017

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

This is to certify that the thesis prepared by Shambel Meressa, entitled: "Assessment of potential causes of construction delay in tunnels; a case study at Awash-Weldiya railway project" and submitted in partial fulfilment of the requirements for the degree of Master of Sciences (Railway Civil Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Approved by the Examining Committee:

Internal Examiner _____ Signature _____ Date _____

External Examiner _____ Signature_____ Date _____

Advisor _____ Signature _____ Date _____

_____

School or Center Chair Person

Declaration

I declare that this thesis entitled "Assessment of Potential Causes of Construction Delay in Tunnels; A Case Study at Awash-Weldiya Railway Project" is my original work. This thesis has not been presented for any other university and is not concurrently submitted in candidature of any other degree, and that all sources of material used for the thesis have been duly acknowledged.

Candidate:

Name: _____

Signature: _____

Acknowledgments

Prior to all, my thanks to the almighty GOD is endless; similar to my usual day to day activities; he gave me strength, commitment, tolerance, or everything important to me in accomplishment of this thesis.

I would like to express heartfelt gratitude to my advisor, Dr. Girmay Kahssay, for his kindness, patience, and valuable guidance throughout the period of this research work. I am grateful to Ethiopian Railways Corporation (ERC), and Addis Ababa University Institute of Technology; School of Civil and Environmental Engineering, for giving me this opportunity and financial support.

I am also grateful to the staff members of ERC, Contractor (Yapimerkezi), and Consultant (Systra MD.) of Awash-Weldiya railway project. Special thanks is to the professionals: who participate in filling of the questionnaire, those share me data and those who gave me valuable comments. I would like to delegate my greatest thanks to Engineer Abdulkerim project manager of Awash-Weldiya railway project and Engineer Biruk, for all the facilities and directions on how to get the required data. Last but not least, I would like to thank my family, who support me to be on this way.

Abstract

Extensive investments in transport are currently being carried out in Ethiopia. A substantial part consists of railway projects with some underground/tunnel constructions.

This research deals with assessment of potential causes of construction delay in tunnels; a case study at Awash-Weldiya railway project which is a new railway line in Ethiopia. The objectives of the research were to: (1) assess the extent of construction delay at tunnels of Awash – Weldiya railway project, (2) identify the key causes of delay and problems encountered during the construction of the tunnels, and (3) to rate the impact of the causes of delay on the construction time of the tunnels.

Questionnaire survey together with desk study was used to collect data on tunnel construction delay. A desk study of 6 completed tunnels on the project were investigated and analyzed using descriptive statistics. From the results it was found that 4 out of the 6 tunnels suffered delay. The rate of delay on the delayed 4 tunnels ranges from a minimum of 12.84% to 119.41% of the scheduled amount for each tunnel. The average delay of phase one tunnels of Awash-Weldiya railway project was 38.8%.

From a number of causes of delay in literature, considering the opinion of professionals of the project 47 causes were identified and prepared as a questionnaire. A total of 17 questionnaires from professionals were collected. The findings from the questionnaire shows that Land acquisition costs and right of way problems, Delays in payment from client, Late in approving documents, and Project location were among the top ten causes of delay. The findings also indicate that the main problems were right of way, flooding, quality, and health and safety problems.

Based on impact all the 47 causes were grouped in to three zones in a risk matrix: consequently, 14 causes had high impact, 31 causes with moderate impact, and 2 causes had minor impact on the construction time of phase one tunnels of Awash – Weldiya railway project.

Key Words: Delay, Risk sources, Tunnel

Table of Contents

Contents Page No

Declaration i
Acknowledgments ii
Abstract iii
Table of Contents iv
List of Tables vi
List of Figures vii
List of Acronyms viii
Chapter One: Introduction 1
1.1 General Background 1
1.2 Problem Statement 2
1.3 Research Objectives 3
1.4 Research Questions 3
1.5 Scope of Work and Limitation 3
1.6 Structure of the Thesis 4
Chapter Two: Literature Review 5
2.1 Project 5
2.2 Project Management 7
2.3 Project Time Management 8
2.4 Schedule 9
2.5 Delay 10
2.6 Types of Delays 11
2.6.1 Critical and Non critical Delays 12
2.6.2 Excusable and Non Excusable Delays 13
2.6.3 Compensable and Non Compensable Delays 14
2.6.4 Concurrent Delays 15
2.7 Risk Sources or Causes of Delay 16
2.8 Delay in Construction 22
2.9 Tunnel 25
2.9.1 Cut and Cover Tunnels 27
2.9.2 New Austrian Tunneling Method (NATM) 28
2.9.3 Drill and Blast Tunneling Method 30
2.9.4 Tunnel Boring Machines (TBM) 32

2.9.5 Immersed Tunnels 34
2.10 General Description of the Project Area 37
2.10.1 Introduction 37
2.10.2 Geology 39
2.10.3 Climate 41
2.10.4 Topography 42
2.10.5 Equipment 43
2.11 Summary of Literature Review 44
Chapter Three: Research Methodology 45
3.1 Introduction 45
3.2 Research Design 45
3.3 Data Collection 46
3.3.1 Questionnaire Design 47
3.3.2 Questionnaire Distribution 49
3.3.3 Data Measurement 49
3.4 Data Analysis 50
Chapter Four: Analysis, Results and Interpretation 51
4.1 Introduction 51
4.2 Extent of Delay at Tunnels of Awash-Weldiya Railway Project 52
4.3 Questionnaire 54
4.3.1 General Profile of the Respondents 54
4.3.2 Risk Sources or Causes of Construction Delay in Tunnels 59
4.3.3 Impact on Time 62
4.3.4 Problems Faced 73
4.3.5 Measures Taken/Mitigation Actions 80
4.4 Validation of Questionnaire Results 81
Chapter Five: Conclusions and Recommendations 82
5.1 Introduction 82
5.2 Conclusions 83
5.3 Recommendations 85
5.4 Suggestions for Future Works 87
References 88
Appendices 92
Appendix A: Questionnaire Form 92
Appendix B: Some Geological Pictures 98

List of Tables

Table 2.1 Delayed tunnels between 1994 and 2005 24
Table 2.2: History of World's longest railway tunnels 26
Table 2.3: Main features of phase one tunnels of Awash – Kombolcha – Weldiya/Hara Gebeya Railway Project (Tunnel Final Lining report No 0005 version 2; 2016). 40
Table 2.4: Schedule of phase one tunnels (Revised Time program, May 16, 2016) 41
Table 2.5: Summary of the Temperature Records along the Project Alignment (Basic Design Report; Report No: 001 version 00; 2014). 41
Table 2.6: Rainfall records along the project alignment (Basic Design Report; Report No: 001 version 00; 2014). 42
Table 3.1 Identified schedule risk sources or causes of delay in the research 48
Table 3.2 Likert scale values 50
Table 4.1 Original and actual time of each tunnels 52
Table 4.2 Construction delay of each tunnels 53
Table 4.3 Work experience of respondents 57
Table 4.4 Level of cause's severity and frequency 59
Table 4.5 Results of project related and contractual relationship factors 62
Table 4.6 Results of client related factors 63
Table 4.7 Results of contractor related factors 63
Table 4.8 Results of consultant related factors 64
Table 4.9 Result of labor related factors 64
Table 4.10 Results of material related factors 65
Table 4.11 Results of equipment related factors 66
Table 4.12 Results of external factors 66
Table 4.13 Result of group of causes 67
Table 4.14 Result of all causes with impact on time 68
Table 4.15 Actual problems faced in the case study 79
Table 4.16 Recommended measures 80

List of Figures

Fig 2.1: Drill and Blast cycle (Tayachew, 2015) 31
Fig 2.2: Study area 38
Fig 2.3: General plan of Awash-Weldiya single track railway line (T4 Excavation and Support design report no 0003 version 0; 2015) 38
Fig 4.1: Percentage of respondents in each type of organization 54
Fig 4.2: Percentage of respondents for each work position 55
Fig 4.3: Educational status of respondents 56
Fig 4.4: Field of specialization of respondents 57
Fig 4.5: Work experience of respondents in the construction sector 58
Fig 4.6: Risk matrix 60
Fig 4.7: Chart of indices of group of causes 67
Fig 4.8: Impact zone of each causes 72
Fig 4.9: Work activities halted due to right of way problems (Weekly progress reports, March 2016). 73
Fig 4.10: Reoccurring flooding problem due to heavy rain (Weekly progress reports, April and May 2016). 75
Fig 4.11: Some of quality related problems (Weekly progress reports, from September 2015 to June 2016) 77
Fig 4.12: Employees were working without safety belts at heights (left) and Presence of dusty atmosphere (right) (Weekly progress reports, January 2016) 78

List of Acronyms

ADM----------Arrow Diagramming Method

CCPM----------Critical Chain Project Management

CPM----------Critical Path Method

D&B----------Drill and blast

EPC----------Engineering Procurement Construction

ERC----------Ethiopian Railways Corporation

GERT----------Graphical Evaluation and Review Techniques

GG----------Gilgel Gibe

GPM----------Graphical Path Method

NATM----------New Australian Tunneling Method

PDM----------Precedence Diagramming Method

PERT----------Project Review and Evaluation Techniques

PM----------Project Management

PMBOK----------Project Management Body of Knowledge

PMI----------Project Management Institute

Q-GERT----------Q-Graphical Evaluation and Review Techniques

RMR----------Rock Mass Rating

SPSS----------Statistical Package for Social Science

SSP----------Successive Scheduling Process

TBM----------Tunnel Boring Machine

YM----------Yapi Merkezi

Chapter One: Introduction

1.1 General Background

A tunnel is an underground passageway with openings at both ends and helps to bypass obstacles without disturbing the overburden (Amani, 2007 and Tayachew, 2015). This long and narrow underground opening starts at the surface of the ground or at an excavation. In tunneling work activities are performed in sequence or starting of the next activity follows the completion of the predecessor activity.

The construction method depends on factors such as ground conditions, ground water conditions, depth, size, and surface constructions.

Generally tunnels can be categorized into three basic tunnel types (Amani, 2007):

1. In-situ/bored tunnels: are constructed without removing the overburden.
2. Cut and cover tunnels: the ground above is removed with trench excavation and then restored; and
3. Immersed tunnels: are constructed beneath water by using precast elements.

The tunnels in the research study area are In-situ type tunnels. The study area is "Awash – Weldiya Railway Project" which consists of 392km long single track line connecting Northern Ethiopia (Weldia city) with the central region (Awash city). The Client is Ethiopian Railways Corporation (ERC) and the Design & Built Contractor is Yapi Merkezi (YM). This Railway project consist of two phases. During the planning stage phase 1 included 7 tunnels, but tunnel 1 was constructed as a cut section. This was because of the low overburden height and suitability of the cut soil as selected material in other activities. Therefore the study focuses on phase one tunnels (six in number) where their construction is completed. Bored/In-situ tunnels can be constructed using different types of methods like: drill and blast (D&B), mechanically by for example road-header or tunnel bore machine (TBM), etc. The conventional method with D&B is the most commonly used method in the study area.

Completing projects on time is an indicator of effectiveness, but the construction process is subject to many variables and unpredictable factors, which result from many sources. As a result of those sources delay in construction becomes a worldwide phenomenon.

This research deals more on construction delay on phase one tunnels of Awash – Weldiya railway project which is a new railway line in Ethiopia. In managing delays different researchers studied the causes of delay in certain geographical areas and for certain type of project. In Ethiopia railway tunneling work is almost a new technology, hence it is difficult to get tunnel construction delay researches specific to its geographical area. Therefore identifying, rating based on their frequency of occurrence and their impact of these delay factors helps in preventing similar delays from happening in future works.

1.2 Problem Statement

Determination and quantification of risks and their impact on project costs and time within the construction of tunnels is described to be one of the most difficult areas. In Awash-Weldiya railway project which is a new railway line in Ethiopia, Evidences show that there is a construction delay in tunnels. Especially this seems more serious issue in tunnel 4 as Employer's representative monthly progress report No. 12 March 2016 shows that the predicted delay for this tunnel is high and difficult to recover. This monthly progress report reveals that, considering the daily excavation progress and compared to the global schedule the predicted delay for excavation work of tunnel 4 is more than 9 months.

Therefore, this research will perform to identify factors and their impact on construction schedule of phase one tunnels including tunnel 4 of Awash-Weldiya railway project, and revises the measures taken to minimize delay in tunnel construction at the case study.

1.3 Research Objectives

The study will be designed to focus on the following main objectives:-

1. To assess the extent of construction delay at Tunnels of Awash – Weldiya railway project.
2. To identify the key causes of delay and problems encountered during the construction of the tunnels.
3. To rate the impact of the causes of delay on the construction time of the tunnels.
4. To propose recommendations.

1.4 Research Questions

The study will be performed to answer the following questions:-

1. What are the factors, which leads to construction delay in tunnel construction?
2. Which causes have highest impact on the project?
3. What measures are taken to minimize the delays during construction of the tunnels?

1.5 Scope of Work and Limitation

The study area of the research focuses on the tunnels of Awash – Weldia railway project. The construction of this railway project had two phases. Phase one which is from Awash to Kombolcha consists of seven tunnels. The construction of Tunnel one was changed as a cut section, hence the research focuses on the remaining six tunnels and their construction was completed till the finalization time of the research. Therefore, the research identifies the occurrence of construction delay, causes of delay and their impact during construction of those completed six tunnels.

In this thesis there were limitations which were encountered throughout the preparation of this research. Unavailability of adequate documented information and unwillingness in the construction firms (Clients, Consultants and contractors) are some of the limitations. The reasons of unwillingness of the firms were: in order not to lose their time and on the contractor side they fear to share data related to time and cost as they are bidders for other similar works.

Another limitation was difficulty in getting claim related data. This was due to that the claims were on progress or they were not settled. This limitation by itself was also an obstacle to identify the

actual type of cause of delay during the construction of the tunnels. In the analysis part cause of delay was used interchangeably with risk sources, but in the questionnaire form only risk source was mentioned which may biased the idea of the respondents.

1.6 Structure of the Thesis

This thesis can be organized in to five chapters as described below:

Chapter one is an introductory part which consist of general background, problem statement, objectives, research questions, scope of work and structure of the thesis.

Chapter two shows literature review of different topics related to the title of the thesis from different researchers work.

Chapter three discusses about research methodology of the research work.

Chapter four presents results and discusses on the findings of the research.

Chapter five contains conclusions and recommendations from what are discussed and gained in the previous chapters.

Chapter Two: Literature Review

2.1 Project

According to PMBOK guide (2013), project is defined as ". . . a temporary endeavor undertaken to produce a unique product, service, or result." This means that a project is done only one time. According to Kim (2005) projects are temporary in nature, with definite start and end dates, their outcome is a unique product or service, and are completed when they met their goals and objectives, then signed off by the stakeholders.

In another guide book by Harold (2009), project is described as any series of activities and tasks that:

- Have a specific objective to be completed within certain specifications
- Have defined start and end dates
- Have funding limits (if applicable)
- Consume human and nonhuman resources (i.e., money, people, equipment)
- Are multifunctional (i.e., cut across several functional lines)

The following are the characteristics of a project (Kim, 2005):

- Projects are unique
- Projects are temporary in nature and have a definite beginning and ending date
- Projects are completed when the project goals are achieved or it's determined the project is no longer viable
- A successful project is one that meets or exceeds the expectations of your stake holders

Though, there are different types of projects, this research concerns on construction project and it is termed as unique with the following things (Construction Extension to (PMBOK), 2000):

- Construction projects, with the possible exception residential projects, do not produce a product as such; but rather a facility that will make or house the means to make a product or provide service facilities such as dams, highway and parks.
- They deal with geographical differences and natural events in every case and may have a significant effect on the environment.
- Often, if not usually, they involve a team of hired specialists in design and construction disciplines.
- In today's world they have to involve many stakeholders, particularly, environmental and community groups that many other types of projects do not.
- Construction projects often require large amounts of materials and physical tools to move or modify those materials.

Successful project can be defined as having achieved its objectives (Harold, 2009):

- Within time
- Within cost
- At the desired performance/technology level
- While utilizing the assigned resources effectively and efficiently
- Accepted by the customer

In order to satisfy its objectives, project needs proper management. Therefore the next section discusses about project management.

2.2 Project Management

As PMBOK Guide (2013) edition, Project management is application of knowledge, skills, tools, and techniques to project activities to meet the project requirements and is accomplished through the application and integration of the project management processes of initiating, planning, executing, monitoring and controlling, and closing. Here it is shown that project management processes are similar with project phases. Project management is defined as the planning, organizing, directing, and controlling of company resources for a relatively short-term objective that has been established to complete specific goals and objectives (Harold, 2009). Furthermore, project management utilizes the systems approach to management by having functional personnel assigned to a specific project.

The PMBOK Guide (2013) recognizes nine project management knowledge areas, but according to the guide book Construction Extension to (PMBOK, 2000), the last four knowledge areas are added as specific to construction projects only. The knowledge areas are:

- Project integration management.
- Project scope management.
- Project time management.
- Project cost management.
- Project quality management.
- Project human resource management.
- Project communications management.
- Project risk management.
- Project procurement management.
- Project safety management.
- Project environmental management.
- Project financial management.
- Project claim management.

From the above listed project management knowledge areas project time management is directly related with the work of this research and requires thorough discussion.

2.3 Project Time Management

For most people, time is a resource that, when lost or misplaced, is gone forever. For a project manager, however, time is more of a constraint, and effective time management principles must be employed to make it a resource.

PMBOK fifth edition (2013), defines project time management as a processes that is required to manage the timely completion of the project. In this guide book project time management processes are listed and described as follows:

- **Plan Schedule Management**: The process of establishing the policies, procedures, and documentation for planning, developing, managing, executing, and controlling the project schedule.
- **Define Activities**: The process of identifying and documenting the specific actions to be performed to produce the project deliverables.
- **Sequence Activities**: The process of identifying and documenting relationships among the project activities.
- **Estimate Activity Resources**: The process of estimating the type and quantities of material, human resources, equipment, or supplies required to perform each activity.
- **Estimate Activity Durations**: The process of estimating the number of work periods needed to complete individual activities with estimated resources.
- **Develop Schedule**: The process of analyzing activity sequences, durations, resource requirements, and schedule constraints to create the project schedule model.
- **Control Schedule**: The process of monitoring the status of project activities to update project progress and manage changes to the schedule baseline to achieve the plan.

According to Construction extension to (PMBOK 2000) there are three additional processes for the construction industry:

- **Activity weights definition**: determining the relative and absolute weights for each project activity.

- **Progress curves development**: analyzing activity weights and project schedule to create progress curves.
- **Progress monitoring**: monitoring project progress

Each of these processes occur at least once in every project and in one or more project phases (if the project is divided into phases). They may overlap each other and correlate in interactions.

2.4 Schedule

Schedules are key documents in the management of construction projects. A project schedule establishes the start date, duration, completion date, and resource needs for each activity in the project. Mistakes in the schedule may cause the project team to allocate resources to the wrong place at the wrong time or may prevent the parties from accurately assessing whether the project is ahead of or behind schedule. Scheduling the construction process is essential not only so that projects can be completed profitably and on time, but also any delays can be evaluated in order to prove entitlement to time and cost compensation. As problems are encountered, the schedule helps project managers rearrange project tasks and resources so that they can meet the primary objectives of time, cost, and quality under limited resource and budget constraints.

The schedule develops as the project moves from its early conceptual phase into the execution phase.

- **Conceptual:** When the scope of the project is being determined, a simple schedule that shows the major tasks and approximate start and end dates is developed to allow senior management to make decisions about the scope of the project. Detail is not required at this stage because entire tasks might be dropped from the scope, or the whole project might not be approved.
- **Master:** If the project is chosen, a master schedule is created. It has major events and dates such as the starting date and the completion date. The master schedule is often part of a contract. Changes to the master schedule must be approved using a documented change process with approval by the project sponsor and client.

- **Detail:** To execute the master schedule, the major activities are broken down into smaller activities and resources are assigned to those activities. The most detailed versions or portions of the schedule may be developed a few weeks prior to the execution of those activities and are called two-week plans. Portions of the master schedule that affect particular vendors might be sent to them so they can provide detailed activities that they would perform.

In present days it is obvious that Project time management involves more complex, computer aided process. The researcher, Bikram (2014) identifies the following Tools and Methodologies available in project management practice for project scheduling. These are Gantt Chart, Arrow Diagramming Method (ADM), Precedence Diagramming Method (PDM), Critical Path Method (CPM), Graphical Path Method (GPM), Project Review and Evaluation Techniques (PERT), Graphical Evaluation and Review Techniques (GERT), Q-Graphical Evaluation and Review Techniques (Q-GERT), Critical Chain Project Management (CCPM), Successive Scheduling Process (SSP), Line of Balance Method, Linear Scheduling Method, Repetitive Scheduling Method, Project Management Software, Simulation Techniques, and Last Planner System.

2.5 Delay

Completing projects on time is an indicator of effectiveness, but the construction process is subject to many variables and unpredictable factors, which result from many sources. As a result of those sources delay in construction becomes a worldwide phenomenon. Thus, it is important to predict and identify problems, causes/sources, and implement the most suitable and economical solutions to prevent further negative impacts of delay.

Previous researchers defined schedule delay by their own words, however it is summed up in to a similar meaning. Focusing on the construction project, delay was defined as the late in progress or actual completion of works compared to the baseline construction schedule or contract schedule (Dayang, 2009). Vast majority of project delays occur during the construction phase, where many unforeseen factors are always involved. In the study by Robel (2014) delay was defined as the slowing down of work without stopping construction entirely which can lead to time overrun either beyond the contract date or beyond the date that parties have agreed upon for the delivery of the project.

From the view of Abubeker (2015) Delay is similar to Time overrun and is the extra time taken to complete the project beyond the scheduled or planned time which is caused by internal and external factors of the project. It is a project slipping over its planned schedule and is considered as common problem in construction projects. To the owner, delay means loss of revenue through lack of production facilities and rent-able space or a dependence on present facilities. In some cases, to the contractor, delay means higher overhead costs because of longer work period, higher material costs through inflation, and due to labor cost increases.

Delay was also defined as the time over run either beyond completion date specified in a contract or beyond the date that the parties agree upon for delivery of a project (Divya.et al, 2015). Another researcher Ismaaini (2014) also defined Time overrun as late completion of activities to the planned schedule due to excusable and non-excusable delay.

As shown in the above definitions Delay and time overrun are the same in most researcher's view, but some researchers differentiate them. For example in the research by Erfan (2014) the definition of delay is the situation where the start of an activity or a project is postponed but time overrun is the situation where the duration of the activity or the project extended. In this research both delay and time overrun are considered the same and there will be no differentiation between them. The definition used for this study is, delay is late completion of activities to the planned schedule due to internal and external reasons.

2.6 Types of Delays

Identifying the delay type helps to check whether additional time extension is warranted or not to a given/required critical activity (Abubeker, 2015). The types of delays can be classified in a way of: excusable or non-excusable delay, concurrent or non-concurrent delay, and compensable or non-compensable delay. These types of delays may occur during the process of the project due to internal or external sources. According to Abubeker (2015) internal sources of delays are arisen from the owner, designers, contractors, and consultants whereas external sources of delays are originated from outside of construction projects such as utility companies, government, subcontractors, suppliers, labor unions, nature, etc.

Similar to Abubeker (2015) various literatures had classified delays in different ways: Delays can be classified as critical and non-critical, excusable and non-excusable, compensable and non-compensable, and concurrent delays (Robel, 2014).

According to Jessica (2014) delays are mainly classified as excusable and non-excusable with excusable delays more categorized in to compensable and non-compensable delays.

In the research by Asif (2009) delays are grouped in to critical and non-critical delays, non-excusable (Contractor caused) & excusable delays, compensable (Owner caused) & non-compensable delays, and concurrent & non concurrent delays.

Generally literatures show that delays are categorized in different ways with point view of different researchers, but more or less the classifications have similarities with each other. Since, identifying of the type of delay helps in providing a correct measure at a right time during running of the project, the detail types of delay are briefly described as follows:

2.6.1 Critical and Non critical Delays

Flow of activities of any construction project may has its own critical path. The critical path is the longest path in the program or flow, in which delay on predecessor activity leads to delay on the successor activities and overall project. Therefore, delays which result in extended project completion are considered as critical delays, and delays that do not affect the project completion date are known as noncritical delays. Non critical activities have total float time. Total float time is an amount of time an activity can be delayed without affecting the end date of the project. However, the ownership of total float is mostly disputable and may lead to critical delay, hence requires a great care during the contract and construction progress. ‘The ownership of total float belongs to: 1) owner, 2) contractor, 3) whoever uses it first, 4) contractor and owner on unequal basis, or 5) contractor and owner on equal basis (Asif, 2009). Allocating ownership of float is critical to update the schedule in regular intervals in order to use it as a time management tool and to analyze time impacts.

The criteria's that determines the project completion date are (Robel, 2014):

- The project type
- Plan and Schedule of the contractor (particularly the critical path)
- The requirements of the contract for sequence and phasing
- The physical constraints of the project- how to build the job from a practical perspective.

2.6.2 Excusable and Non Excusable Delays

Based on the clauses in the contract any type of delay can be categorized as either excusable or non-excusable delay (Abubeker, 2015). Excusable delays are delays that can be excused to a contractor from performing within the contract period and justified with an extension of time and sometimes extra money. Excusable delays are those not attributable to the contractor's actions or inactions and typically include unforeseen events. These events are beyond the contractors and sub-contractors control and are without their default. This type of delays can have an impact on non-critical activities which need a more detailed analysis to determine whether additional time extension is warranted, or if the reduction of float time can be justified. Excusable delays can be further classified into delays with compensation and without compensation. In compensable excusable delay the contractor is granted with additional money and time, but in non-compensable delay the contractor is given only extra time in accomplishing the work.

Examples of the causes of excusable delay includes (Abubeker, 2015; Jessica, 2014; and Robel, 2014):

- Acts of God or of the public enemy,
- Acts of government,
- Fires,
- Floods,
- Epidemics,
- Quarantine restrictions,
- General labor strikes,
- Freight embargoes,
- Unusually severe weather,

- Intervention by outside agencies,
- Differing site conditions or concealed conditions,
- Owner-directed changes,

Non-excusable delays are arisen from events that the contractor could have foreseen or prevented, but failed to do so. Due to this the owner entitled to claim any delays to the project with the help of the terms and conditions stipulated in the contract. These claims are run with penalty and or liquidated damages.

Some examples of causes of non-excusable delays taken from researches by (Abubeker, 2015; Robel, 2014) are listed as follows:

- Late performance of subcontractors,
- Untimely performance by suppliers,
- Faulty workmanship by the contractor or subcontractors,
- A project-specific labor strike caused by the contractor's unwillingness to meet with labor representatives or by unfair labor practices,
- Contractor cash-flow problems,
- Accidents on the site caused by the contractor's negligence or lack of preparations,
- Late delivery of the contractor's furnished materials and equipment.

2.6.3 Compensable and Non Compensable Delays

Compensable delays are caused by the owner, the designer or the owner's agent, as a result the owner provides a time extension and recovery costs related to the delay to the contractor. Such compensable delays are excusable delays, suspensions, or interruptions to all or part of the work caused by owner's not attainment of an obligation, stated in the contract.

Some examples of causes of compensable delays are listed below (Jessica, 2014):

- Defective Drawings or Specifications.
- Improper Site Preparation
- Failure to Provide Access
- Failure to Supply Materials or Labor

- Failure to Provide Plans/Approve Shop Drawings.
- Failure to Coordinate Parallel Prime Contractors
- Failure to Give Timely Work Orders.
- Failure to Make Timely Payment to Contractors
- Failure to Inspect/Over-inspection
- Work Suspensions
- Excessive Change Orders
- Failure to Accept Completed Work
- Acceleration

Non compensable delays are caused by third parties or incidents beyond the control of either the owner or the contractor and are not belong to any of the parties.

The major elements that represent of non-compensable delays can be grouped in to three and described as follows (Jessica, 2014):

1) Unforeseen events: unforeseeable causes generally refer to future events, not existing causes. By contrast, conditions of which the contractor should have been aware are not considered unforeseeable.

2) Events beyond the contractor's control: these are cases in which work on the project is impossible.

3) Events without fault or negligence: such events are those in which the contractor is blameless, such as acts of God and labor or material shortages beyond what was expected at the time the contract was made.

In the research by Robel (2014), the causes of non-compensable delays are described as unusual weather conditions, natural disasters, wars, national crises, floods, fires or labor strikes. Generally the decision on the type of the delay depends on the issues of the contract.

2.6.4 Concurrent Delays

Delays based on the interrelation of the above delay types with respect to their duration and time of occurrence are described by the terms of "independent delays", "serial delays" and "concurrent delays" (Jessica, 2014). Independent delays are delays that occur in isolation or without other

consecutive or simultaneous delays while serial delays occur in sequence consecutively and not overlapping with each other on a particular network path.

On the other hand, when two or more independent delay causes which are attributable to different parties are overlap or affect the completion date of the project at the same time period are often termed as "concurrent delays" (Jessica, 2014).

Concurrent delay includes a combination of two or more independent causes of delay occurring within the same time frame and other names of concurrent delay are overlapping delays, simultaneous delays, commingled delays, and intertwined delays (Robel, 2014).

Concurrent delays arise when one event causes a delay simultaneously with another event. For example, if an owner denies access to a project site for two weeks, and a severe storm prevents a contractor from working on the project for one of two weeks as well, there will be a concurrent delay of one week. The contractor will be able to recover for delay damages for one week, as a severe storm is not a cause of delay that is compensable and would have prevented the contractor from performing even if the owner did not deny access to the site.

2.7 Risk Sources or Causes of Delay

Risk is an uncertain event or condition that, if it happens, will have a positive or negative impact on project objectives (PMI, 2009). According to Kerzner (2009) risk is a measure of the probability and consequences of failure to achieve the defined objectives of a project. Risk is the effect of uncertainty on objectives (ISO 31000, 2009).

It is shown that from the above definitions risk is linked with objectives. The relation between the objectives and the risk allows for adequate risk management process. While assessing the significance of risk and the methods of handling it the objectives of the project should be considered.

The measurable performance parameters or objectives of tunnel construction are described as follows (Spackova, 2012):

1. Completion of the construction on time
2. Completion of the construction within the budget

3. Fulfillment of the technical requirements
4. Ensuring safety during the construction
5. Minimization of impact on operation of adjacent structures
6. Minimization of damage to third party property
7. Avoidance of negative reaction of media and public

Risk is the effect of factors/risk sources on those objectives. This study mostly focuses on effect of risk sources on the construction time, the other performance parameters are not considered yet.

Therefore, for this research risk source can be defined as a factor which lead the tunnel construction to time overrun. Since, these factors are obstacles in accomplishing the objectives of tunnel construction, the researcher believes that identifying the factors, rating of their impact and suggesting remedial measures helps in avoiding or minimizing similar time overruns of future tunnel construction works.

Various researchers identify different types of factors related to construction time of tunnels. Some of them are listed below:

According to Spackova (2012) the time of tunnel construction primarily depend on: geological conditions (e.g. mechanical properties of the ground, frequency and orientation of discontinuities), hydrological conditions, frequency of changes of the geological and hydrological conditions - (in)homogeneity of the environment, cross-section area of the tunnel, length of the tunnel, inclination of the tunnel, depth of the tunnel/height of overburden, affected structures and systems (requirements on maximal deformations, protection of water systems and environment, operational constraints), quality of planning and design, and construction management and control, quality of construction works. In addition, the author termed the factors which influence the objectives of the construction as uncertainties, and categorized them in to usual uncertainties or factors causing deviation in the normal time and cost range and extraordinary events (failures) causing significant unplanned changes of the expected project development.

Factors causing changes in time identified by Isaksson (2002) are: Normal risk factor: factors causing deviations in the normal spans. And, Undesirable event: event that causes major unplanned changes in the tunneling process. Examples of normal risk factors stated by this author are performance-related factors like the efficiency of equipment and labor, and financially-related factors like the market situation. Similarly examples of undesirable-event-related risks described by the author are tunnel collapses and unforeseen changes in the geological conditions that cause damage or total modification to the excavation method.

Another researchers Debasis et al (2011), identify common risk sources of underground corridor construction of metro rail project activities, which includes: delay in approval of detailed project report, land acquisition problems, design mistakes, improper technology selection, late approval and permit, joint venture problems, financial and investment risks, political risks, environment related risks, geo technical risks, major / minor accidents during execution, unforeseen heavy rain, force majeure like flood, fire earthquake etc, labor agitation and strikes, inflation, delayed payment from client, and delayed payment to subcontractor. In the study by Mauriya and his colleagues (2010), inadequate investigations, deficiencies in contracting practices, delayed financing, and delayed decisions were identified as the main challenges of tunneling work.

The following researchers are also studied on causes of delays not directly on tunnels but on construction and public projects as general on which tunnel is included.

Erfan (2014) reveals that delay causes are country or region specific and different delay factors from articles supports this statement. He reviewed about 35 construction delay related articles that studied/written in continents of Asia, Africa, America, Europe and Australia. From these articles the author listed 131 delay factors, and identifies the following eight most common delay causes: poor site management, change, poor planning, poor communication, financial problem, poor labor productivity, material management, and late decision-making. In perspective of Divya.et al (2015) causes of delay were grouped in to seven namely owner-related, contractor related, consultant-related, materials related, equipment related, labor related, and external factors. These groups were consists of totally 31 causes. After ranking of all these causes, the main causes for delay were ineffective planning and scheduling by contractor, rise in prices of materials, late in revising and approving design documents by owner.

According to Ahmed et al (2016), public projects in Qatar included data of 122 public road, building, and drainage projects that were constructed in between 2000 and 2013, had a 72% time delay. The authors also reports the possible causes to project delays as poor management and control systems, manpower low quality, construction material and equipment shortage, inappropriate estimation of massive scale of projects, harsh summers, and funding constraints of private projects.

In the study by Ismaaini (2014), the researcher reviewed 80 journals from different countries and identifies a total of 69 time and cost overrun factors. Based on frequency (min 1), 35 of the 69 significant factors that cause time overrun were identified. These factors were grouped into seven main categories namely: contractor's site management related factors, design and documentation related factors, financial management related factors, information and communication technology related factors, labor management related factors, material and machinery related factors, project management and contract administration related factors. These 35 factors were rated by respondents in order to identify high risk factors on time overrun in construction projects of Malaysia. Consequently 12 high risk factors were: poor site management and supervision, incompetent subcontractors, inadequate planning and scheduling, frequent design changes, mistakes and errors in design, change in the scope of the project, delay preparation and approval of drawings, lack of coordination between parties, slow information flow between parties, lack of communication between parties, shortages of materials, and late delivery of materials and equipment.

The researcher Abubeker (2015), who studies about 'Factors affecting time and cost overrun in road construction projects in Addis Ababa', had identified the most important causes of time overrun as delay to furnish and deliver the site (right of way problem), financial problems and improper planning. These most important causes were identified from a total of 32 causes that were grouped in to 8 namely project related factors, owner responsibility, contractor's responsibility, consultant responsibility, materials, labor and equipment, contractual relationship and external factors. 65.7% of public construction projects which were implemented in Rwanda between 2009 and 2012 were delayed and the factors were delayed payments, financial deficiencies for both the contractors and the client, and material procurement (Musirikare and Julius, 2016). In this study, it was observed that among 38 construction projects in Gasabo District,

25 were delayed by a total of 292 weeks. The average delay was 58% of their cumulative expected period.

In the view of researchers Henry et al (2013); the five most important causes of delays in Uganda's public construction projects were found to be changes to the scope of work, delayed payments, poor monitoring and control, the high cost of capital and political insecurity and instability. This study was done based on Uganda's public construction projects which were constructed between 2003 and 2008. The methodology used was desk study and questionnaire. In the questionnaire 20 different types of causes were identified and the questionnaire was distributed to 247 professionals in order to rate these causes. Robel (2014) assessed and identified delay on Addis Ababa's light rail transit construction project that includes one cut and cover tunnel. Due to the fact that the project was in execution phase, the researcher asked if the project is exposed to delay, then 90% of the respondents agreed that the project is exposed to delay and the main causes were identified as delayed site handover and right of way, lack of coordination with the stakeholders, delayed external work due to public agencies and poor economic conditions resulting time and cost overrun and several claim requests.

Dayang (2009) studied that 'Construction project delays in Johor and Sabah regions'. In his study, he identifies 56 causes with eight groups of contractor related delays, client related delays, consultant related delays, material related delays, contract-relationship related, plant/equipment related, labor related delays, and external factors. In order to get the opinions of the contractors, consultants and clients who participated in the two regions, he distributed 50 questionnaires to each region. Finally he found that the most significant delay causes in Johor were 'contractor' financial difficulties', 'poor subcontractor performance', 'shortage of manpower', 'poor site management/supervision' and 'slow payment of completed work'. Contrarily in Sabah, the important causes of delay were led by 'poor site management/supervision', 'low speed of decision making by client', 'slow payment of completed work', 'contractor' financial difficulties' and 'improper planning of works by contractor'. According to Ashwini and Rahul (2014); 57% of 205 projects delayed in Indian construction was due to brief reasons of delay in land acquisition, delay in equipment erection, inadequate mobilization by the contractor, delay in forest clearance, fund constraints, change in scope of work, cancellation of tender, law & order problem, delay in supply of equipment, slow progress of civil work, escalation in cost.

Zinabu (2016), in his study, he identifies the five most significant causes of delay from 41 listed causes that rated based on the perception of 140 professional respondents from client, contractor and consultant. Therefore, according to his study the five most significant causes of delay in Ethiopian construction were cash flow problem, mismanagement, improper planning, slow decision making and late delivery of material and equipment. Another researcher, Ghazi (2015) also studied on 49 bridge and road projects in Saudi Arabia with an average delay of 39%. The most severe causes were land acquisition, contractors' lack of expertise, haphazard underground utilities (line services), and re-designing. According to Siraw (2016) 80% of roads constructed from 2000 to 2005 E.C. (Ethiopian Calendar) under Addis Ababa city road administration were suffered time overrun. The most important causes of time overrun were found to be slow site clearance, contractors' financial problems, Inflation, progress payments delay by owner, inaccurate cost estimation, and delay in commencement.

On the work of researchers Asish et al (2015), the top ten significant causes of construction delays regarding road infrastructure projects were identified as: delay due to land acquisition, environmental issues, delay in progress payment, ineffective project planning and scheduling, poor site management and supervision, rework due to errors, delay in approving design documents, poor coordination between owner and other parties, financial closure, and change order by clients.

According to Ravisankar and his colleagues (2014), 299 of 572 (around 53%) construction projects in India reported on 30.11.2010, were delayed with a range from 1-225 months. In this study the top ten important causes which were identified from a number of causes are: shortage of unskilled & skilled labor; design changes by owner or his agent during construction; fluctuation of prices; high waiting time for availability of work teams; rework due to errors; delay in financial support by owner to the contractor (Stage by stage payment); geological problems on site; poor site management &Inaccurate site investigation; wrong selection of type /capacity of equipment; and bad weather conditions /natural disasters (flood, earthquake).

2.8 Delay in Construction

A lot of researchers studied status of delay in construction which might be project specific, country specific or as a general. In this section, some of the reviewed studies in this research; in construction as general followed by in tunnels as specific are presented.

Abubeker (2015) revealed that in road construction projects in Addis Ababa out of 10 completed road construction projects, 100% or all of the projects faced time overrun with a range of minimum 25% to a maximum of 264.38%. In the same way according to Siraw (2016), 80% of roads constructed from 2000 to 2005 E.C under Addis Ababa city road administration were suffered time overrun. In the findings of Tadesse et al (2016); with the help of responses from 69 professionals who participate in the construction sector the amount of schedule slippage in Ethiopia ranges between 61-80%.

According to Ahmed et al (2016), public projects in Qatar that were constructed in between 2000 and 2013, had a 72% time delay. Another researcher Ghazi (2015), also studied on 49 bridge and road projects in Saudi Arabia with an average delay of 39%.

In the study by Ashwinis and Rahul (2014), report of Dec, 2012 of construction projects in India shows that out of 205 projects around 57 % projects are experiencing time overrun. In some of the projects the time overrun was very huge. For instance, around 28 projects are having time overrun in range of 13 to 24 months, 23 projects have delay in range of 25 – 60 months & 14 projects have delay of 61 & above. Big concern is on five projects which were experiencing maximum delay of between 120 and 201 months. Surprisingly 4 of the 5 projects were railway projects. Similarly in the view of Ravisankar and his colleagues (2014); 299 of 572 (around 53%) construction projects in India reported on 30.11.2010, were delayed with a range from 1-225 months.

In the study by Energy Department of World Bank (1985), the survey of 64 World Bank-financed hydroelectric projects indicates that geological difficulties had caused major cost overruns and completion delays for 23 projects (36% of total). At the time of survey 41 projects were completed or their evaluation reports were received whereas the remaining 23 projects were without evaluation reports. Among 41 projects with evaluation reports 13(32%), encountered geological complications during construction that causes a delay of from 18% to 100%.

Among 23 projects without evaluation reports 10(43%), faced geological problems causing Completion delays of one to four years. Tunneling was the single most recurring component of civil works affected by geological problems. Among 23 projects with geological difficulties 18 encountered tunneling problems. This number represents 28% of all hydroelectric projects. Problems included landslides, undetected faults, weak rock conditions, soft and watery zones, presence of clay formations, etc. These 23 projects with problems were from 20 different countries which implies delay as a worldwide phenomenon. Since the projects were constructed in different countries of the world, Finchaa hydroelectric power in Ethiopia was one of the assessed projects. In this project there was a delay of nine months (23%) in commissioning the first unit. The delay was mainly due to the poor rock formation which was encountered when excavating the road tunnel. This required the installation of arch supports and lining throughout the entire length of the tunnel. Similar trouble was encountered in the construction of the power tunnel which necessitated many steel supports. These problems were also the main causes of the cost overrun.

Tayachew (2015), had studied about the design and construction approaches of the GG III hydropower tunnels in Ethiopia and has found design and construction problems related to the applied rock mass classification system. The problems during construction were: using incorrect construction procedures of NATM, installation of improper ground excavation supports, and no installation of instrumentations and drainage holes (in the diversion tunnels). Due to these problems, rock and shotcrete wedges failure occurred at various locations of power and diversion tunnels, and a tunnel section collapsed in the central diversion tunnel. A worker has been lost due to the rock wedges failure in the manifold of the right power tunnel. Due to the collapsed tunnel section, the unexpected quantity and various types of rock supports, ground improvement materials, various construction techniques, a construction of additional 63.25m access tunnel (adit), etc. were used in the remedial works. Only the remedial works took almost nine months, from May 2007 to February 2008. Though, the amount is not clearly recognized here, it is obvious that delay was occurred. Similarly the author assures that there was a problem during the construction of GG II hydropower tunnel. The problem was collapse or failure in some sections of the tunnel during construction and even after three months operation. The cause of the collapse was suspected as the presence of a major fault, perhaps an old river bed, hidden behind a thin diaphragm of hard but fissured rock. As a result of this there was humid mud with a pressure of

40 bar which is almost 6 times the design pressure (7 bar) and had been so big as to break the rock diaphragm and apply a high concentrated load on a few segments or causing them to crush. Therefore, remedial measures and repairing works were performed and took additional time. Especially Dredging as much as 40,000 m3 of mud continuously for 2 years (between October 2006 and August 2008) could indicate the presence of delay on the project.

As mentioned by Hervé and his colleagues (2006), 14 tunnels that constructed in between 1994 and 2005 had delay. The project name, construction method, type of loss, causes of loss and number of delay in months of those tunnels is described in the next table.

Table 2.1 Delayed tunnels between 1994 and 2005

Year of completion	Project	Construction method	Type of loss	Cause of loss	Delay in months
1994	Great Belt Link, Denmark	TBM	Ingress of water		12
1994	Munich, Germany	NATM	Collapse	Faulty design (soil)	10
1994	Heathrow Express Link, UK	NATM	Collapse	Faulty workmanship	14
1994	Taipei Metro, Taiwan	TBM	Ingress of water	Faulty workmanship	12
1995	Los Angeles Metro, USA	TBM	Collapse	Faulty workmanship	15
1995	Tapei Metro, Taiwan	TBM	Ingress of water	Faulty workmanship	18
1999	Hull Yorkshire Tunnel, UK	TBM	Collapse	Faulty design	26
1999	Anatolian highway, Turkey		Earthquake	Earthquake	36
2000	Taegu Metro, Korea	Cut and cover	Collapse	Faulty design/work	9
2002	Autoroute A86 – Rueil, France	TBM	Fire		6

2003	Shanghai Metro	Freezing	Collapse	Faulty workmanship	47
2004	Singapore Metro, Singapore	Cut and cover	Collapse	Faulty design/work	18
2005	Barcelona Metro, Spain	NATM	Collapse		24
2005	Kaohsiung Metro, Taipei	TBM	Collapse	Faulty workmanship	24

2.9 Tunnel

A tunnel is an underground passageway with openings at both ends and helps to bypass obstacles without disturbing the overburden (Amani, 2007 and Tayachew, 2015). This long and narrow underground opening starts at the surface of the ground or at an excavation. In tunnelling work activities are performed in sequence or starting of the next activity follows the completion of the predecessor activity.

Tunnels bring us different types of benefits. They are viable means to minimize potential environmental impact such as traffic congestion, pedestrian movement, air quality, noise pollution, etc. In addition, they help in minimizing visual intrusion; to protect areas of special cultural or historical value such as conservation of districts, buildings or private properties. They are a means for other sustainability reasons such as to avoid the impact on natural habit or reduce disturbance to surface land. Tunnels improve the connections between two junctions and shortens route length. Sometimes it is a must to use underground space for storage, power and water treatment plants, civil defence and other activities in view of limited space, safe operation, environmental protection and energy saving (Dimitrios, 2005).

Due to their benefits tunnels are continuously constructed in the world. Started from thousands of years ago Engineers and miners developed and used quite impressive methods and technologies in the long history of tunnelling and mining works (Christoph, 2011). According to Shigeru (2015) history of World's longest railway tunnels is reviewed in the table below:

Table 2.2: History of World's longest railway tunnels

Tunnel name	Year of completion	Country	Length of tunnel (m)
Box	1841	UK	2880
Mount Cenis	1871	France & Italy	12,234
St. Gotthard	1882	Switzerland & Italy	14,892
Simplon I	1906	Switzerland & Italy	19,803
Simplon II	1922	Switzerland & Italy	19,824
Daishimizu	1982	Japan	22,221
Channel	1994	UK & France	50,450
Seikan	1988	Japan	53,850

At this time (2017) Gotthard Base Tunnel (1996 - 2010), 57.1 km long is the longest tunnel in the world. The whole system is consisting of 151.84 km of underground constructions like tunnels, shafts and passages.

There are many types of tunnels and can be classified in many ways (Christoph, 2011):

Based on functional requirement tunnels can be classified as: mining, military or protection, transportation, utility, storage and plant, religious /historical structures, and scientific tunnels. On the other hand, by considering the depth of overburden tunnels can be either shallow or deep set tunnels.

In terms of their construction method tunnels can be categorized as immersed, mined, and cut and cover tunnels. Another criteria to classify is the type of ground they traversed, accordingly tunnels may be in soft ground or in hard rock. Tunnels are also classified based on their cross-sectional shape as rectangular, elliptical, circular, and horseshoe.

The construction method depends on factors such as ground conditions, ground water conditions, depth, size, and surface constructions. Some of the construction techniques and methods commonly utilized in present practice are cut and cover, New Australian Tunnelling Method, Drill and blast, TBM, and Immersed tunnels. These main tunnelling technologies are discussed as follows:

2.9.1 Cut and Cover Tunnels

The cut & cover tunnels are constructed directly from the surface by excavating a trench or a cut and installing of temporary walls to support the sides of the excavation, roofing the tunnel and covering it with fill material. In limited space tunneling braced or tied-back/anchored, trench-type excavation and backfill are run. Generally the necessary activities to be conducted during this method are trench excavation, tunnel construction and soil covering of excavated tunnels.

As the depth of the tunnel increases the cost of excavation increases, thus the method is suitable for construction of shallow tunnels and is often used for the construction of beginning and end parts of the bored tunnels (Spackova, 2012). Cut and Cover method is economical in a depth from about 10 - 12 m but it depends on project parameters like ground conditions, available space, objectives on the surface and influences of existing traffic (Christoph, 2011). Based on available space on the site an open cut slope or a permanent or temporary structure is used to dig and stabilize the trench. To use the open cut slope which is a quite cheap method, slopes should be erected in a proper angle. In case of limitation/circumscribe sensible objects to the trench, permanent or temporary structures (temporary structures like: sheet piles, soldier piles or lagging walls & common permanent supports are slurry walls or pile walls) are applied to support the trench. In this work dewatering of the trench and the deflection of the permanent or temporary support walls are the most important things to be considered.

The stability of the soft ground, impact on the existing underground services & utilities and traffic disruption in urban areas are the negative features of cut and cover method. To avoid interference and to keep continuity of traffic flow temporary decking may be used while the construction works proceeds underneath till final backfilling and surface restoration (Eva, 2003).

There are two types of construction methods to build cut and cover tunnels (Jeremy et al; 2009):

- Bottom up - structure independent of support
- Top down –tunnel roof and ceiling parts of support

2.9.2 New Austrian Tunneling Method (NATM)

The New Austrian Tunneling Method (NATM) was developed by the Austrians Ladislaus von Rabcewicz, Leopold Müller and Franz Pacher in the 1950s (Eva, 2003; Špačková, 2012). The name was given in 1962 to separate it from the 'Austrian Tunneling Method', today described as the 'Old Austrian Tunneling Method'. As defined by the Austrian Society of Engineers and Architects, the NATM "…constitutes a method where the surrounding rock or soil formations of a tunnel are integrated into an overall ring-like support structure. Thus the supporting formations will themselves be part of this supporting structure (Eva, 2003)." Those Austrians or developers of this method proved that lining is not the main support of the tunnel, but the ground by itself is also very important. As a result, they reduced the lining thickness near to 20 cm, and used sprayed concrete instead of the brick lining in order to give the benefit of a tight and firm coupling between the lining and the ground; whereas the brick lining left a space between the support and the surrounding ground. Furthermore, it was important that the sprayed concrete lining (SCL) was supported by systematic anchoring. The observed information of the response of the ground due to the tunneling process is used to determine the required support and construction sequences. Since the calculation techniques available at that time were not enough, they used displacement monitoring to prove the efficiency of their support.

About 22 principles were published by Müller and Fecker (1978) to fully describe the NATM. Almost all of the principles are used as key elements of most of the tunneling methods used today.

NATM or New Austrian Tunneling Method also known as sequential excavation method (SEM) is a method of tunnel construction used from small to large openings in various types of ground ranging from rock to soil. Its objective is to control deformations and thereby mobilize and maximize the self-supporting capacity of the ground. Excavation is carried out in increments and numerical sequence, which is supported with initial and final lining and a waterproofing system in between them. A definition was given by Rokahr (1995) to differentiate NATM from other tunneling methods: 'NATM is a support method to stabilize the tunnel perimeter by means of sprayed concrete, anchors and other support, and uses monitoring to control stability.'

From this definition NATM includes: Support by sprayed concrete; Support by systematic anchoring if necessary; using measurements to control the effectiveness of the support; and a

flexible approach to support measures, i.e. increasing or decreasing the support according to the geological conditions.

The method is not NATM when the following terms are occurred:

- excavation by TBM;
- support by segmental lining;
- no support at all;
- the full overburden is supported;
- No flexible approach is adopted for the support.

Generally initial and final ground support, monitoring, and choice of excavation cross-section are the main features of NATM (Christoph, 2011; Erik, 2014; and Eva, 2003).

Tunnel construction process in NATM is as follows (Erik, 2014; Eva, 2003; and Špačková, 2012):

1. Excavation.
2. Sealing the exposed ground if necessary.
3. Mucking.
4. Installation of lattice girders and the first layer of reinforcing bars or mesh reinforcement, and application of sprayed concrete. Depending on the quality of the ground the support might be installed first before the spoil is removed.
5. Second layer reinforcement installation and application of more sprayed concrete.
6. Installation & tightening of anchors (if necessary) and shotcreting of anchor heads.
7. Construction of inner lining.

The factors that must to be considered in designing/choosing of excavation and support sequence for the construction of an underground space are (Eva, 2003): Tunnel size, required geometry, type of support elements and their quantity, ground condition and behavior, construction space, surface settlement, and the available labor force.

Though, NATM has been used effectively for the construction of large tunnel cross sections in very poor ground and with careful execution in poor rock, Failures, mostly at or near the tunnel face are occurred due to: unexpected geologic or groundwater conditions, faulty application of insufficient shotcrete strength or thickness, belated placement of ground support, or advancing the excavation before the shotcrete has achieved adequate strength.

2.9.3 Drill and Blast Tunneling Method

Drill and blast tunneling method can be used in ground ranging from low strength hard rock to hardest rock. Due to the vast range, it is advantageous in highly changeable ground conditions.

Cases that makes drill and blast preferable to TBM and Road header are (Erik, 2014 and Milad, 2015):

- Relatively short in length: machines with high investment costs are not economical in short tunnels.
- Highly hard ground condition: this leads the cutter tools of the machines to be worn frequently, which implies additional cost for replacement.
- Tunnel with cross sectional profile other than circle and in a very large tunnel profile.
- Applicability in vast range of geological formation.
- Difficult curvature to be advanced by TBM.
- Good construction speed in hard ground.
- Easily changeable in varying geology and geometry.

Activities in this tunneling technique are performed in a series manner, therefore this makes the tunnel technique to be time consuming or its construction speed to be slower than TBM tunneling.

In the excavation cycle of drill and blast tunneling method the following activities are conducted (CECW-EG, 1997; Christoph, 2011; and Erik, 2014): drilling, charging, stemming, blasting, ventilation, mucking, scaling and supporting.

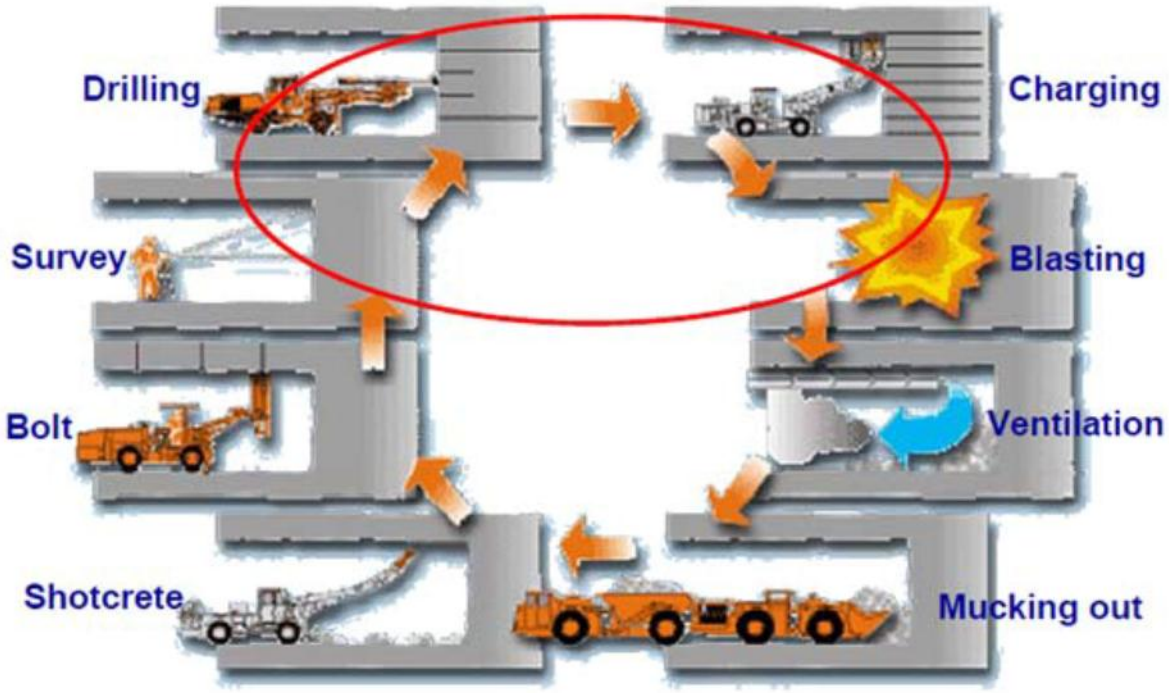


Fig 2.1: Drill and Blast cycle (Tayachew, 2015)

The tunnel face can be excavated either by full face method, or by partial face excavation method (CECW-EG, 1997; Christoph, 2011). In full face method the whole tunnel face is blasted in one round and it is efficient. However, in large tunnels large mechanical equipment is required and it is not suitable in unstable rock.

Therefore, in case of large cross section, vibration control is intensive and stability purpose in poor ground conditions partial face excavation (with head, bench, invert and side drifts) is preferable. In heading and benching method first the top portion is advanced, then roof lining is followed using the bottom part as supporter to facilitate the work. In this method drill holes can be either vertical or horizontal and less explosive is needed. The drift excavation method with partitions (center drift, side drift, top drift and bottom drift) can also be used in a very large tunnels and very weak rocks. In this method it is possible to easily see the problems and apply corrective measures on time, vibration and damage are reduced, and drifts helps in facilitating roof lining. But, small drifts are unsuitable for large scale machine and construction speed may be decreased.

The negative sides of drill and blast are hazards of explosives (toxic gases and dusts), vibration, noise, shock waves, air pollution and its cycle dependency (Christoph, 2011; and Erik, 2014). Especially hazards of explosives, vibration, shockwaves, air pollution and noise are very serious issues in urban tunneling. Therefore these issues should be considered before they affect surface and sub-surface structures and human beings.

2.9.4 Tunnel Boring Machines (TBM)

As its name indicates TBM is any machine which is used to advance tunnel excavation, but in our case TBM can be explained as a machine used to excavate a tunnel with circular profile (current available size from 1m diameter up to 19.25m), and it consists a large rotational cutter head arranged to excavate various types of ground conditions (Erik, 2014).

TBM may be referred as a large diameter cylindrical shield, equipped with a cutterhead, with cutting tools and muck buckets; systems to supply power, cutterhead rotation, and thrust; a bracing system for the TBM during mining; equipment for ground support installation; shielding to protect workers; and a steering system on which all these assembled to excavate a tunnel (CECW-EG, 1997).

Although, TBMs are sometimes designed to a single project with a specific diameter and certain ground conditions, these days TBMs are becoming well known and projects are designed related to the diameter of available machines. The cutter head is redesigned to the expected specific ground conditions of the project. In order to use TBM the geology along the route of the tunnel should be consistent, as the cutting tools are suitable for only a small variation of material characteristics. The combination of different cutting tools on the cutterhead can increase the application of TBMs to a greater range of ground conditions.

Most TBMs were used to construct a tunnel with a circular profile. But, currently they are used in various shapes of tunneling with application of technological advancement such as multi-face shield tunneling machine, rectangular or horseshoe-shaped shield tunneling machine, and built-in parent-child shield tunneling machine (Milad, 2015).

In urban tunneling TBM is preferable than D & B method, which causes less disturbance (noise & vibration) to the surrounding environment. In addition TBM provides smooth surface in the

internal wall of the tunnel, hence it is easy to support. Generally TBM has its own advantages and limitations (CECW-EG, 1997; and Milad, 2015).

Advantages of using TBM are:

- Higher rates of advance in producing the required bores
- Continuous operations
- Less rock damage/less over break
- The excavation formation is less damaged/not weakened by the operation, hence less ground support is required.
- Uniform muck characteristics
- Greater worker safety or no risk of collapse of tunnel excavation face
- Cost reduction in tunnels with length greater than 2 km
- Well suited for soft soil tunneling

Limitations of TBM tunneling are:

- High initial/capital cost and it is expensive for short tunnels.
- In hard rock tunneling cost of wear and tear is high.
- Suitable only for circular cross section
- Limited flexibility in response to highly variable geological conditions
- It takes long time to mobilize or own the machine
- Jam during tunneling cause high downtime and cost increase
- High installation cost and Expensive drive-in operations

A TBM is a system to advance a tunnel that provides continuous functions of thrust, torque, rotational stability, muck transport, steering, ventilation, and ground support.

According to CECW-EG (1997); shift time, penetration rate, utilization, advance rate, and cutting rate are some of the parameters that are used to evaluate TBM system performance.

The activities of tunnel construction by using TBM are Excavation and support of the undercut area, Excavation of the tunnel and tail tunnel, Disposal of excavated material from the tunnel face, Hoisting excavated material to ground level, Lining the tunnel, Extending the services and rail tracks, and Excavation and support of the removal shaft (Milad, 2015). In the activity of lining if segmental lining is used as support of the ground, there is a gap between the segments erected with

in the tunnel shield and the excavated ground. The gap is injected/filled with cement slurry, then rigid connection of lining and ground is achieved, thus helps to prevent material movement. Another challenge during performing of the activities is to keep the groundwater, soil and cement slurry out of the tunnel shield. This can be proceed by using tail seals.

To conclude tunnel boring machines can be classified as Open face boring machine (suitable for excavation of stable soils) and closed face shielded machine (an option for less stable soils like; silt or sand) (Milad, 2015). In addition this classification can be termed as tunnel boring machines in hard rock and soft ground.

2.9.5 Immersed Tunnels

Immersed tunnels are structures which built beneath water and consists of precast tunnel elements which are mostly made of either reinforced concrete or steel. An immersed tunnel is constructed under water by first made the place watertight with temporary bulkheads, then tunneling is conducted using pre-fabricated elements constructed in the dry at some distance from the tunnel location (Jeremy et al, 2009). One of the key design criteria for this type of tunnel, in contrast to bored tunnels, is the need to ensure adequate stability against uplift. Immersed tube tunnels are ideal for crossing rivers and estuaries in urban areas. Due to the location just under the water body, this method can be considerably cheaper than TBM tunneling through the ground under the water. The surface infrastructure (roads, rail track) needs to connect to the tunnel but is constrained by limits on gradients that are suitable for cars or trains. Therefore, the deeper the tunnel, the longer this lead in section needs to be. As bored tunnels are generally constructed at a greater depth, which is necessary for ground stability during construction, they are often longer than immersed tube tunnels and hence more costly. Bored tunnels may also be technically more challenging due to the high water pressures, which can be a problem during construction. However, great care is required when construction of immersed tunnels in order not to disturb the living things of the water body.

The two types of immersed tube tunnels are steel shell and concrete (Jeremy et al, 2009). Steel shell also can be classified as single, double and sandwich shell construction. In a single-shell construction, there is actually an internal concrete lining and an outer steel shell plate that has been stiffened internally. This outer steel shell acts as a permanent watertight membrane, as the

formwork for the internal concrete lining and as the structural element to carry the flexural forces before and after placement.

In the double-shell construction, there is an additional outer steel shell. The area between the two steel shells provides a convenient space for additional ballast. The layer between the two steel shells is a ballast and reinforced concrete, thus double steel shell is stiffer than single shell. However, it may require internal bracing till the tunnel element is placed to its final position. In sandwich construction there are inner and outer load carrying steel shells acting jointly with a structural concrete layer sandwiched in between them. Plates and L-shaped ribs are used in order to stiffen the internal surfaces of the steel shells and provide the connection required for composite action with the internal un-reinforced concrete. This internal un-reinforced concrete carries compression loads whereas the steel shells carry the tension loads. The double layer in this method provides good protection against leaks, however, it is complex and each construction step or activity needs careful application. These steel shell elements have sufficient flexibility and ductility, and unlike concrete elements they are not affected by settlement, shrinkage and creep effects.

Rectangular reinforced concrete shell elements are generally preferable to be used for tunnels with four or more traffic lanes, particularly where concrete is more economical than steel, as they are better suited for the rectangular traffic clearance gauge than the semicircular shape of the steel tunnel cross section. One of the main problems in concrete shell elements is crack, which can be decreased by reducing construction joints, reducing water-cement ratio, and reducing heat of hydration. Crack due to Heat of hydration can be mitigated with including concrete cooling using refrigerated pipes cast into the concrete, mix design, low heat cement such as ground granulated blast furnace cement, shielding from the elements and proper curing. Due to weight and heat of hydration concrete elements are limited to a length of about 20m, whereas steel elements are prepared up to a length of 130m (Christoph, 2011). But a big problem with steel elements is the deformation.

The activities to be performed during immersed tunnel construction are (Jeremy et al, 2009):

- Excavation of the required trench and Fabrication of pre-cast elements in a shipyard, in a dry dock or in a casting basin, depending on the type of construction and available facilities.

- These pre-cast elements, are temporary closed with bulkheads, then floated/transported, handled and towed to their position in the tunnel alignment.
- Elements reaching to their final destination, sinking of these floated and towed pre-cast elements into a pre-dredged trench by filling temporary water ballast tanks inside the elements, then placing of elements to the required position, joining together and watertight connections are formed.
- Preparation of the foundation, this may be before immersion of the elements and after trench excavation or by placing the elements on temporary foundation pads and subsequently jetting sand into the gap between the elements and the trench bottom.
- Placing the immersed tunnel properly, then backfilling should be placed uniformly on both sides of the structure to avoid imbalance lateral loads on the structure. The backfill usually consist of Selected locking fill (to secure the elements laterally), General Backfill (to the sides and top of the tunnel structure, also providing an impact-absorbing load-spreading layer above the tunnel), A rock protection blanket (to provide scour protection), and Rock-fill anchor-release bands (are sometimes provided to bring the anchor to the surface and close the space between the hook and the shank).
- The tunnel is then sealed and the water ballast pumped out.

2.10 General Description of the Project Area

2.10.1 Introduction

The study area of the thesis is on the Awash- Weldiya /Hara Gebeya railway project which is a new railway line being constructed between the Ethiopian towns Awash and Weldiya and passes through Kombolcha. The Client (Employer) is Ethiopian Railways Corporation (ERC) and the Design and Built Contractor is the Turkish company Yapı Merkezi (YM). The Employer's representatives are SYSTRA, a company organized and existing under the laws of France and jointly with MULTI-D Engineering Consultancy PLC, a company organized and existing under the laws of Ethiopia. The contract type is EPC/Turnkey with contract time for completion forty two (42) months after the commencement date and contract price one point seven billion United States dollar (1.7 billion US Dollar). Date of commencement was 18.10.2014. Total railway route to be constructed by Yapı Merkezi is 428 km including 392km long single track line, 25 km long station tracks and 11 km long service lines. Besides the railway tracks, this project also involves 4 terminal stations and 6 way stations. In this big project there are also a number of Infrastructures like:- Tunnels, Bridges, Overpasses and Underpasses.

Generally figure 2.2 shows the route of the study area.

Awash - Kombolcha – Weldiya/Hara Gebeya Railway Project is represented by red color.

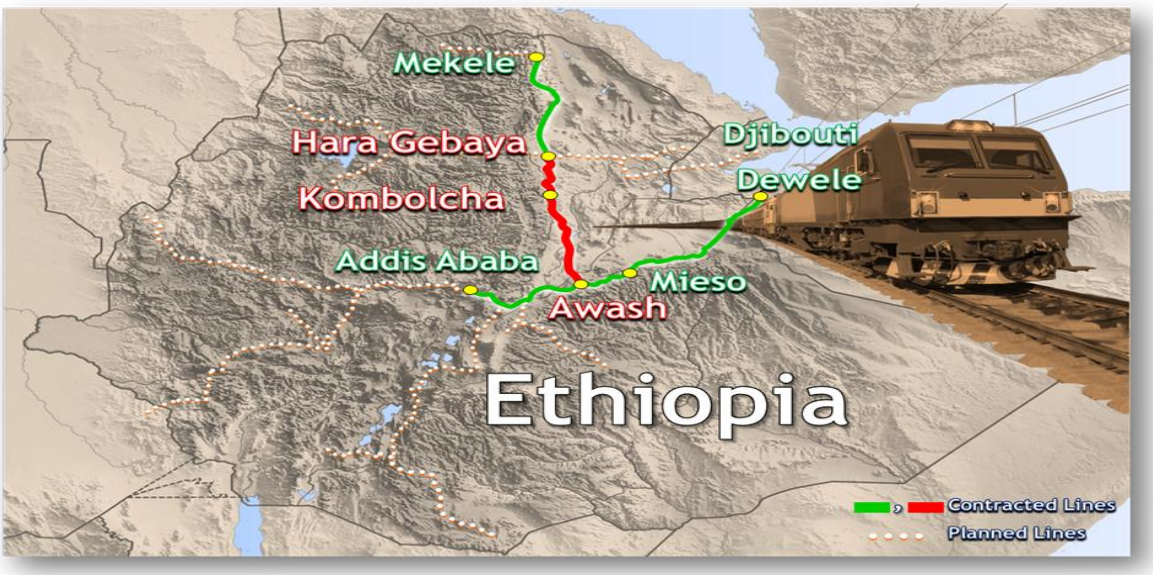


Fig 2.2: Study area



Fig 2.3: General plan of Awash-Weldiya single track railway line (T4 Excavation and Support design report no 0003 version 0; 2015)

2.10.2 Geology

Based on geological data, the project area comprises four major groups of litho startigraphic units (Basic Design Report; Report No: 001 version 0; 2014). These are:

- Eocene volcanics
- Oligocene-Miocene volcanics
- Upper Miocene volcanics
- Quaternary volcanics

Along the Project alignment, four threats that could endanger the railway performance as geological hazard are (Basic Design Report; Report No: 001 version 0; 2014):

- Problematic / expansive soils
- Swampy or Marshy stretches
- Inundation areas

This railway project consists of two phases from Awash to Kombolcha classified as phase one and from Kombolcha to Weldiya known as phase two. Phase one includes seven tunnels. Based on preliminary geological data, it results that tunnels will be predominantly executed within rock formations belonging to Tertiary age, in particular within:

- Kemise Formation "Tk", also known as Trachyte Formation "Tt" (Upper Miocene period) formed by Rhyolite, ignimbrite, tuff and ash.
- Molale Ignimbrite "Tmi" (Oligocene-Pliocene period) composed by Yellowish grey slightly weathered ignimbrite with rhyolitic tuff.
- Ashangi Formation "Tas" (Eocene period) composed by black and dark grey, fine-grained to coarse grained basalt and Volcano clastics sediments.

Main features including the expected geological conditions of phase one tunnels of Awash – Kombolcha – Weldiya railway project which are the concerns of this research is indicated in Table 2.3 below.

Table 2.3: Main features of phase one tunnels of Awash – Kombolcha – Weldiya/Hara Gebeya Railway Project (Tunnel Final Lining report No 0005 version 2; 2016).

Tunnel No.ID	From chainage (approx.)	To chainage (approx.)	Length [m] (approx.)	Max. Overburden [m] (approx.)	Expected Geology
1	116+463.478	116+784.478	321.0	42.3	Tt, Trachyte Formation
2	149+167.479	149+355.478	188.0	42.4	Tk, Kemise formation
3	164+130.000	164+515.000	385.0	45.0	Tk, Kemise formation
4	178+090.000	179+560.000	1530.0	322.15	Tas, Ashangi Formation and Tk, Kemise formation
5	184+055.038	184+458.038	403.0	43.85	Tas, Ashangi Formation and Tk, Kemise formation
6	185+450.038	185+772.038	322.0	80.45	Tk, Kemise formation
7	261+450.000	261+737.000	290.0	48.6	Tas, Ashangi Formation

Though accessing full geological report of construction progress is difficult, some available pictures are presented in appendix B.

Tunnel one was eliminated or constructed as a cut section. Therefore the research is mainly focused on the construction schedule of the remaining six tunnels. Considering the geological report and other parameters the schedule of each of the six phase one tunnels is depicted in the following Table (Revised Time program, May 16, 2016):

Table 2.4: Schedule of phase one tunnels (Revised Time program, May 16, 2016)

Tunnel Name	Scheduled Time			
	Start	Finish	Duration (days)	Total Float
T_2	03/06/15	02/12/15	170	523
T_3	29/05/15	14/05/16	327	371
T_4	08/02/15	01/09/16	531	269
T_5	17/06/15	24/05/16	318	362
T_6	21/08/15	02/10/16	380	240
T_7	21/04/15	11/12/15	218	515

Total float is the amount of time by which an activity in a project network can be delayed without affecting the project's completion date.

2.10.3 Climate

2.10.3.1 Temperature

Mean annual temperature of Ethiopia ranges between 0°C to 30°C depending on topography: 0°C to 16°C; over 2500m above the sea level, 16°C to 30°C between 1500m and 2500m above sea level (Basic Design Report; Report No: 001 version 00; 2014).

Mean monthly temperature of the project area ranges between 5°C to 35°C (Source: Studies by consultants for Lot 10, 12, 13):

- South zone (eg. Awash): 10°C to 35°C
- Middle zone (eg. Kombolcha): 5°C to 30°C
- North zone (eg. Weldia): 5°C to 30°C

Table 2.5: Summary of the Temperature Records along the Project Alignment (Basic Design Report; Report No: 001 version 00; 2014).

City	Awash	Abayater	Shewa Robbit	Efeson	Kemisse	Kombolcha	Haik	Merssa
Tmax (˚C)	41.3	38.0	38.8	38.0	37.6	34.1	34.4	38.6
Tmin (˚C)	2.3	9.0	4.6	0.4	3.0	1.5	-2.6	0.0

2.10.3.2 Rainfall

Seasonal rainfall in Ethiopia is driven by the migration of the Inter-Tropical Convergence Zone. Most of Ethiopia experiences one main wet season from mid-June to mid-September up to 350 mm per month in the western regions. Part of northern and central Ethiopia also have a secondary wet season and considerably less rainfall from February to May (Basic Design Report; Report No: 001 version 00; 2014).

In these regions the long rainy season (June – September) and short rains (March - May) are locally referred as "Kiremt" and "Belg" respectively. The rest of the months (October to February) are dry period. During Kiremt the peak mean monthly rainfall varies from 50 mm to 275 mm. In dry months (October to February) the mean monthly rainfall is in the range of about 5 mm and 35 mm (Basic Design Report; Report No: 001 version 00; 2014).

Table 2.6: Rainfall records along the project alignment (Basic Design Report; Report No: 001 version 00; 2014).

City	Mean Annual		Mean for Kiremt		Mean for Belg	
	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days
Awash	620 mm	66	339 mm	38	165 mm	17
c.o.v.	0.22	0.15	0.24	0.16	0.39	0.35
Kombolcha	1017 mm	99	649 mm	58	232 mm	24
c.o.v	0.16	0.12	0.22	0.14	0.39	0.33
Mekelle	568 mm	61	454 mm	46	91 mm	11
c.o.v	0.22	0.18	0.27	0.20	0.67	0.45

2.10.4 Topography

The Project is characterized by a Flat (48.7%), Rolling (38.2%), Mountainous (31.33%), and Escarpment (8.2%) terrains both longitudinally and in the transverse directions (Muna, 2015). In addition altitude of some cities along the project is; Awash (900m), Hara Gebeya (1600m), and a maximum of 2200m in between Hayk and Kombolcha (Basic Design Report; Report No: 001 version 00; 2014).

2.10.5 Equipment

While executing the Tunnels onsite, Contractor was equipped with the following machineries (Awash-Weldiya railway project, Weekly Progress reports; 2015 and 2016):

- Drill Jumbo: Sandvick DT820, ATLAS COPPO 282, ATLAS L2D
- Umbrella Arc Drill: Tamrock Zoom track
- Excavator: Hitachi/Komatsu with hydraulic hammer, Doosan 300 with hydraulic hammer, KOMATSU PC200
- Telescopic handler: JCB
- Front loader: HİTACHİ ZW220, KOMATSU WA470, HYUNDAI HL740
- Shotcrete machine: PM500, TÜNELMAK ROBOT, MEYKO POTENZA, PUMPUSTER PM 5P
- Standard excavator: HITACHI ZAXIS 210, HITACHI ZAXIS 250, HITACHI ZAXIS 216
- Man lift: JCB, ATLASS Coppo
- JCB-CAT 432
- Dump Truck: Volvo 1,2,3,4,5,6,8 and Fatih

2.11 Summary of Literature Review

The literature review was done through previous studies, internet, construction management books, and related journals. From the discussion and explanation under the topic of literature review, a lot of information regarding the concept of delays as well as the causes of delays in construction project has been identified. This would be used to develop the questionnaire survey in order to collect data from the targeted respondents.

It has been learnt from the literature review that Delays occur in every construction project and the magnitude of these delays varies considerably from project to project. Some projects are only a few days behind the schedule; some are delayed over a year. So it is essential to identify the main causes of delay in order to minimize and avoid the delays in any construction project.

It has been also learnt from literatures that delay occurs everywhere around the world and its main causes differ from country to country and from project to project.

It can be seen from the literature review that delay is a long time problem of construction project. It seems that it is not easy to fully avoiding or eliminating delay from construction projects. Even if more researches are made on delay in construction as general, there are few or limited researches specific to tunnel. Especially in Ethiopia railway tunneling is a new construction. Therefore, it is difficult to get similar researches. By taking this in to consideration this thesis mainly focuses on assessing the status of the delay and identifying the main causes of delay on phase one tunnels of Awash-Weldiya railway project.

Chapter Three: Research Methodology

3.1 Introduction

The previous chapter literature review explored and provided sources which articulated methods for the data collection, analysis and exposition, with respect to the objectives of the research. This part shows the chronological of research methodology and discusses the methods of capturing the data needed and the methods of conducting the research in order to achieve the objectives. It is essential to describe the methodologies used throughout this research to ensure all the data and information gathered is reliable and to show that it is systematically collected and analyzed. The raw data obtained from the respondent (professionals) and project archival documents will be analyzed and studied in depth before deriving conclusion. This chapter is organized in sections covering research designs and methods adopted; data collection methodologies adopted; and methods used in analyzing data.

3.2 Research Design

The strategy performed in this research was first start with problem identification which had made through unstructured literature review, archival study and informal discussion with client, Contractor, Consultants as well as professionals in the sector; and then the research design was formulated. Then data and information sources were determined based on the formulated research design. On the basis of the data and information sources the research instruments were decided; and available documentary sources relevant to the research were reviewed. The review includes books, journals, articles, thesis papers, internet sources, and archival documents of the project such as progress reports, contract document, overall project reports and correspondence letters. The data was gathered from the head office of ERC and the construction site. The document search was mainly intended to collect variables related to tunnel construction, and construction delay.

Finally, after an in-depth review of literature and desk study, contact was made with professionals and questionnaire was distributed in order to get their professional opinion based on their experience. Upon obtaining the desired data, checking and sorting of data had done. The data was then analyzed. This was followed by thorough discussions in order to draw a conclusion and to forward recommendations based on the findings of the study.

The research was both qualitative and quantitative in nature. Some of the data collected was in descriptive form while some of the data was in numeric form. The research was also used a descriptive and exploratory survey design.

3.3 Data Collection

Data collection is the most critical part since the accuracy of the data obtained will determine the success or failure of the research. The data on any research is either or both of primary and secondary. The primary data is the original information collected by the researcher for a specific purpose and secondary data refers to that information which have already been collected, analyzed, documented and published by some other researchers or people. The data in this study was collected by using both primary and secondary data sources.

The primary data was obtained through observation, discussion, and questionnaire directed to professionals related to tunnel construction works in Awash – Weldiya railway project. Observation is one of the primary data collection tools and helps to visualize the components of the tunnels, the activities performed, portals and the construction methods of the tunnels. Similarly, discussion by asking questions to the professionals strengthens the idea gathered by literature review, questionnaire, archival document and observation. This means it helps to briefly describe the point which is targeted.

The secondary data were obtained from internal and external sources. Internal sources were the archival documents or includes contract documents, progress report of the completed tunnels in the case study, overall project reports and correspondence letters were investigated thoroughly which were very important in identifying the recurrent problems related to construction schedule delay, and in assigning and identifying of causes of delay. The external secondary data sources used in this research were internet, thesis, journals, books and different articles in published documents.

3.3.1 Questionnaire Design

The questionnaire was developed to assess the perceptions of tunnel professionals of Awash – Weldiya railway project regarding to causes of construction delay, problems occurred during construction of phase one tunnels of the project and their recommendations on what mitigation actions should be taken. Questions in the questionnaire form were created, identified and examined based on problem statement, research objectives and the information gathered from literature review. A thorough checking for the questionnaire has been made to evade any errors and also to ensure only relevant questions is included in the form. The design and structure of the questionnaire was subsequently rechecks by experienced professionals for any correction and reasonable amendment. After the form had been checked, it was made into a number of copies and ready to be distributed.

The questionnaire form consists of three main sections. These sections are introduction, general profile of respondents, and construction schedule risk sources/causes and mitigation actions. The introduction part describes the title of the research, the objectives of the research, about the researcher and assures the confidentiality of the feedback of respondents. The second part general profile of respondents includes position, organization (Client, Consultant or Contractor), address for further contact, educational status, field of specialization, and work experience of respondents.

In the third part forty seven different types of factors of construction delay for underground structure or tunnels were identified from literature review. The identified factors were grouped in to eight groups namely: project related and contractual relationship factors, client related, contractor related, consultant related, labor related, material related, equipment related and external factors. Grouping was made based on literature review and revising the responsibility of each party on the contract document. The causes in each group are listed in table 3.1 below:

Table 3.1 Identified schedule risk sources or causes of delay in the research

1. Project related and contractual relationship factors	**5. Labor related factors**
Short contract duration	Labor shortage
Legal disputes	Unqualified workforce/ Shortage of technical personnel (skilled labor)
Type of contract	Low productivity level of labors
Type of bidding	Labor agitation and strikes
Change orders	High cost of labor
Lack of constructability	Labor Absenteeism
Lack of Communication	**6. Material related factors**
Inaccurate quantity take – off	Material shortage
Rock and soil suitability	Delay in delivery of materials
Project location	Damage of materials
2. Client related factors	Late procurement of materials
Delays in payment from client	Unreliable sources of local & imported materials
Difficulty in financing project/ Funding Problems	**7. Equipment related factors**
Delay in obtaining permits	Equipment breakdown and maintenance problem
Additional work	Shortage of equipment
Client Knowledge	Low productivity of equipment
Land Acquisition Costs and right of way problems	**8. External factors**
3. Contractor related factors	Inflation/Relative Price Changes
Rework due to errors	Weather issues/ Bad weather
Disputes on site	Traffic restriction
Ineffective planning	Unavailability of utilities
Mistakes in design documents	Force Majeure risks like flood, fire earthquake etc.
Inadequate experience	Unexpected Ground Conditions
Major and minor accidents during execution	Exchange Rate
4. Consultant related factors	Social and cultural impacts
Late in approving documents	
Poor coordination/ Poor Project Management	
Poor quality control	

These factors were rated based on their frequency of occurrence and level of impact on time in the case study by respondents/tunnel professionals. In addition, respondents were also encouraged to cite and rate additional causes thought to extend the construction duration of the tunnel project by overall (if any). In this section respondents were also asked to identify the main problems faced and measures taken during construction of the completed phase one tunnels of Awash-Weldiya railway project.

Both close and open ended questions were asked in the questionnaire. The close ended questions had a number of choices of possible answers and the respondents selected whatever they feel was most appropriate. The closed ended questions were selected because they are easier to assess and answer considering how busy the respondents were.

Open ended questions were used only in few places where the response options were relatively wide and not known. The form of the final version of the questionnaire is indicated in the appendix.

3.3.2 Questionnaire Distribution

The target population of the research are tunnel related professionals of Awash – Weldiya railway project. Since the professionals participated in tunnel related activities were very limited, the total population was used in the questionnaire survey. After identification of the number of respondents and had made a number of copies of the questionnaire form, the next step was distributing of the questionnaires. There are different ways of questionnaire distribution such as: email, postal, in hand, etc. In this research most of the questionnaires were distributed with the means of in hand and few questionnaires by email.

3.3.3 Data Measurement

In order to be able to select the appropriate method of analysis, the level of measurement must be understood. For each type of measurement, there is an appropriate method that can be applied. In this research, ordinal scales were used. Ordinal scale is a ranking or a rating data that normally uses integers in ascending or descending order. Based on Likert scale respondents were asked to rate the risk sources in terms of frequency of occurrence and their impact on time. Three point likert scale for frequency of occurrence and five point likert scale for severity of impact on time was used.

The scales are presented in table 3.3 as follows:

Table 3.2 Likert scale values

Likert scale value	Frequency of occurrence	Severity of impact on time
1	Low	Very low
2	Medium	Low
3	High	Moderate
4		High
5		Very high

3.4 Data Analysis

After data is collected analysis and discuss on the results of the analysis is the next step of the research work. The data collected for qualitative and or quantitative method analysis will be only from the completed tunnels (six in number). As previously discussed in section 3.4 the data to be analyzed was collected mainly from two sources which are questionnaire and archival documents. In the questionnaire problems and mitigation actions were identified and summarized in the analysis part. In addition the causes of tunnel construction delay were rated according to their frequency of occurrence and severity of impact on time. For each variable, the mean value of the respondents' frequency rating and impact rating were determined and named as frequency index and severity index respectively. Accordingly rank was given and the severity and frequency levels were identified. Using these values and risk ranking matrix the risk sources were categorized as major, moderate or minor.

On the other hand archival documents were used in identifying problems, and in assessment of time performance of each completed tunnels. The time performance was checked by using the number of days in between schedule start and end date minus number of days in between actual start and end date divided by number of days in between schedule start and end date.

During analysis of the data Excel spreadsheet was used and the data for analysis and the result was in the form of table, graph, and chart. The analysis was conducted in perspective with the research objectives.

Chapter Four: Analysis, Results and Interpretation

4.1 Introduction

This chapter shows the analysis and describes the results and interpretations of the data gathered by means of literature review, by taking report documents, questionnaire, observation, and discussion. The results and interpretations below are devised in to two parts in line with the objectives of this research and also the way of data gathering. The first part consists of original and actual completion time of each completed tunnels (six in number), which is taken from report documents of the project. This helps in identifying the presence of delay and its extent.

The second part is the questionnaire that filled by tunnel related professionals of Client, Contractor and Consultant of Awash-Weldiya rail way project. In the second part the following headings are discussed:

- Respondent profile,
- Risk sources and their impact on construction Time of the tunnels,
- Measures taken to minimize the risk sources, and
- Problems faced during construction of the tunnels.

4.2 Extent of Delay at Tunnels of Awash-Weldiya Railway Project

The time to be assessed here is the time taken to accomplish main Civil works such as portal excavation, tunnel excavation and supporting, water proofing, invert concrete, lining concrete, precast floor (walkway) installation, escape tunnel wall, entry and exist structure concrete works, etc. In addition some side works of Mechanical and Electrical are included, but since the project is under-construction, elemental works which are not critical were not completed till the time of data surveying. The original/scheduled time was taken from the Global Schedule of the project. On the other hand the actual construction time was taken from tunnel progress report documents of the project. The required data is presented in table 4.1 below:

Table 4.1 Original and actual time of each tunnels

Tunnel Name	Scheduled Time			Actual Time		
	Start	Finish	Duration (days)	Start	Finish	Duration (days)
T_2	03/06/15	02/12/15	170	09/06/15	20/07/16	373
T_3	29/05/15	14/05/16	327	10/09/15	16/10/16	369
T_4	08/02/15	01/09/16	531	27/04/15	18/03/17	633
T_5	17/06/15	24/05/16	318	13/01/16	25/12/16	315
T_6	21/08/15	02/10/16	380	22/01/16	18/12/16	304
T_7	21/04/15	11/12/15	218	23/03/15	17/07/16	441

Having this data, the analysis and result which contains the original duration, actual duration, their difference and percentage of schedule delay is shown in table 4.2. The actual duration is determined by counting the calendar days in between start and finish. Whereas the percentage of Delay or Time overrun is calculated using the following equation (equation 4.1).

$$\%\ of\ Delay = \frac{actual\ duration - original\ duration}{original\ duration} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

Table 4.2 Construction delay of each tunnels

Tunnel Name	Original Duration in days	Actual Duration in days	Difference in days	Delay in %
T_2	170	373	203	119.41
T_3	327	369	42	12.84
T_4	531	633	102	19.21
T_5	318	315	-3	-0.94
T_6	380	304	-76	-20
T_7	218	441	223	102.29

As shown in table 4.2 above T_5 and T_6 had a negative delay percent. This indicates that their actual construction duration was less than their scheduled duration. Similarly delay in T_4 was not as long as the anticipated value by consultant during the first three to four execution months, which was estimated above nine months delay. The reduction of delay in tunnels 3 and 4, and avoiding delay in tunnels 5 and 6 was mainly due to: advance the construction in both entrance and exit sides, execute with additional crews, and additionally working with night shifts plus in some of the tunnels the support class was A3 and not require final concrete lining.

In contrast, there was high delay in tunnels 2 and 7. The delay existed in tunnel 2 was highly related with the weakness and variability of the soil which in turn related with the geotechnical investigation. The support class fully changed from A3 in to A4, thus requires inner concrete lining which takes more time than that of shotcrete support in A3 support class. In addition, in tunnel 2 construction was performed only in one side that may last twice of the duration taken by advancing with in both sides simultaneously. The delay in tunnel 7 also had its own reasons such as advancing only in one side, and as it was the first tunnel for the project there was quality problems like inadequate concrete cover which led in to disagreement between parties and on and off of the activities in the tunnel.

4.3 Questionnaire

In this topic analysis, result and interpretation of the data acquired from the questionnaire are going to be discussed. Here sub-topics such as Respondent profile, Risk sources and their impact on construction Time of the tunnels, Measures taken to minimize the risk sources, and Problems faced during construction of the tunnels will be discussed as follows.

4.3.1 General Profile of the Respondents

In this part the general profile of the respondents like type of organization, position, educational status, field of specialization and work experience (in construction as general, in railway, in tunnel as general and railway tunneling specifically) are depicted as follows:

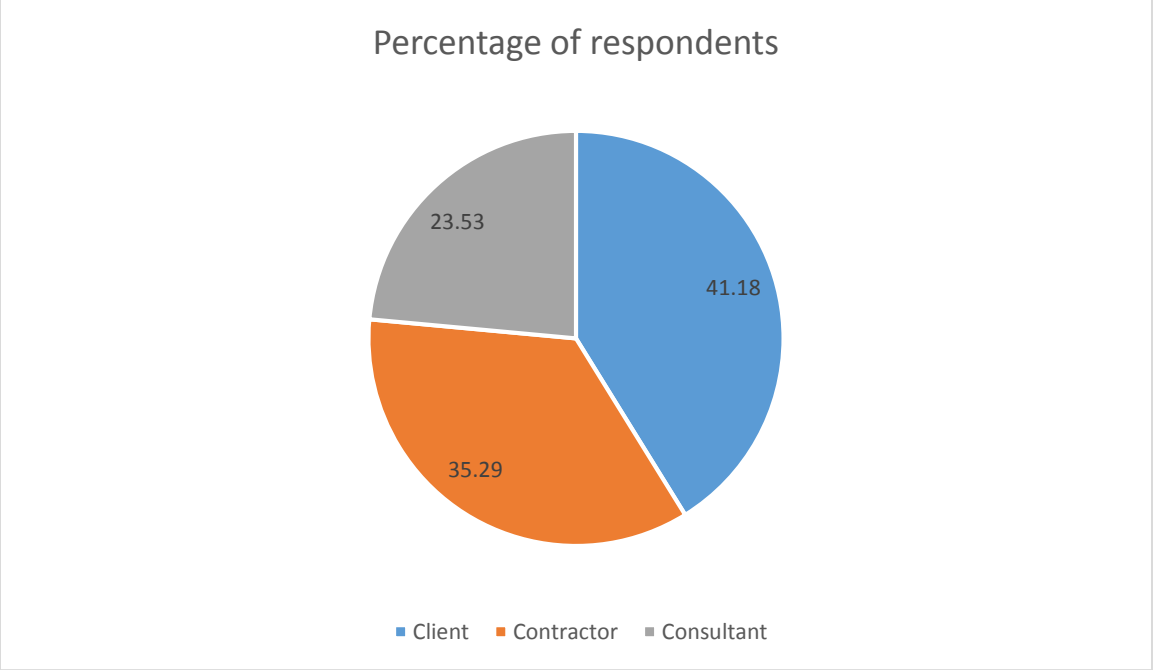


Fig 4.1: Percentage of respondents in each type of organization

Client has highest participants with 41.18% followed by Contractor of 35.29% participants and Consultant shares 23.35% of the total respondents. These respondents are professionals who are directly or indirectly related to the tunneling activities in the project.

The position of the respondents is categorized in to Construction Manager, Tunnel Engineer, Office Engineer, Section Manager and Sub-Section Manager. The number of respondents for each category of position is described in chart below.

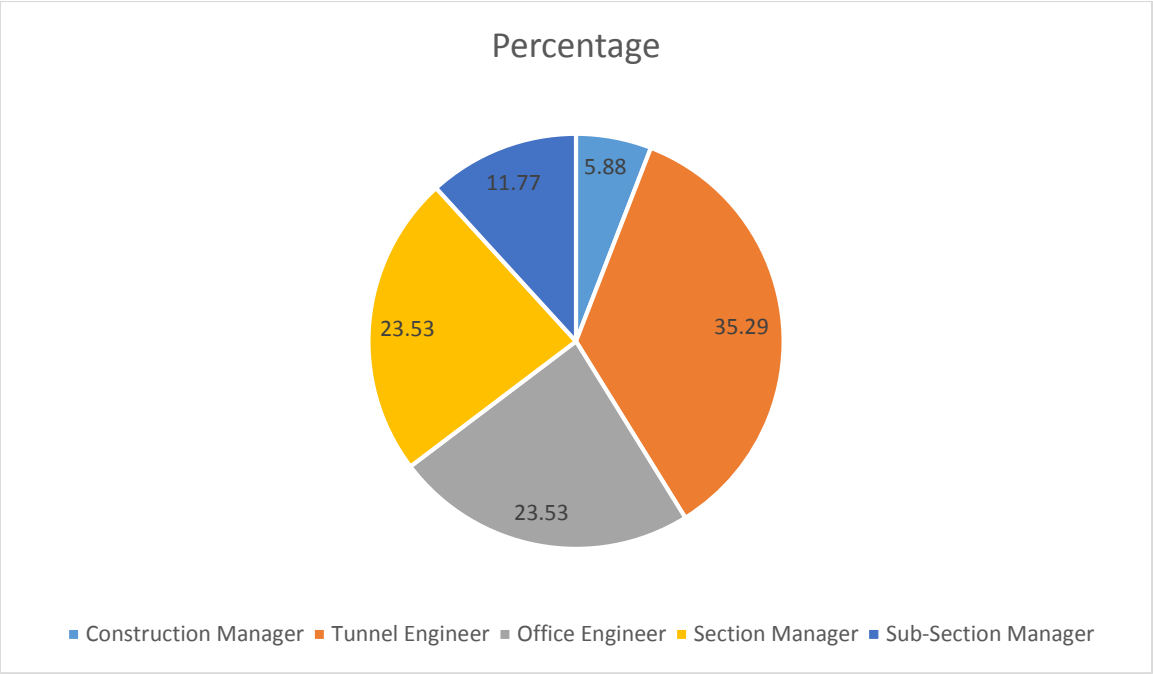


Fig 4.2: Percentage of respondents for each work position

Most of respondents are Tunnel Engineers which shares 35.29% of the total respondents. This is followed by section and sub-section managers with 23.53% respondents each. The researcher believes that, the variety of the position of the respondents helps in getting different types of information with respective of various point of view of the professionals.

The educational status of respondents in the questionnaire was classified as BSc, MSc, PhD and others. Therefore, based on the response of the respondents their Educational status and number of respondents is depicted in the following figure.

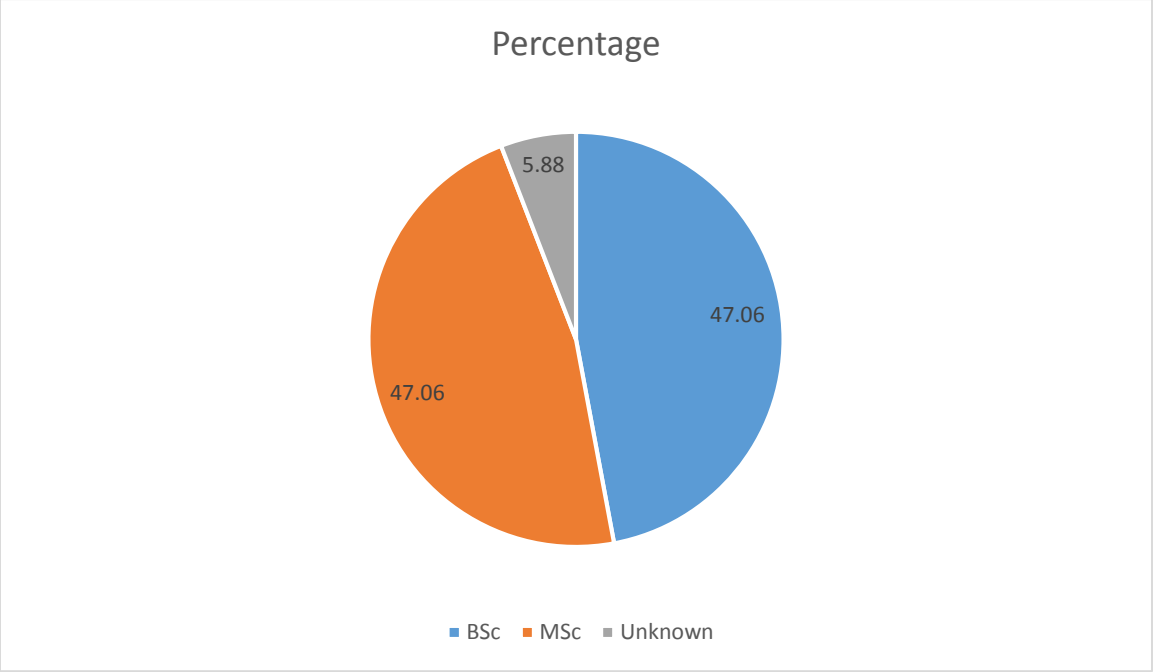


Fig 4.3: Educational status of respondents

The result above shows that respondents are literate, half owe BSc and half owe MSc or 47.06% each, except the one respondent that not clarify his educational status.

Other profile described here is field of specialization of respondents. In the questionnaire respondents were asked to choose their field of specialization from options of Railway Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, or if any other to be specified by respondents. The results from respondents are discussed as follows:

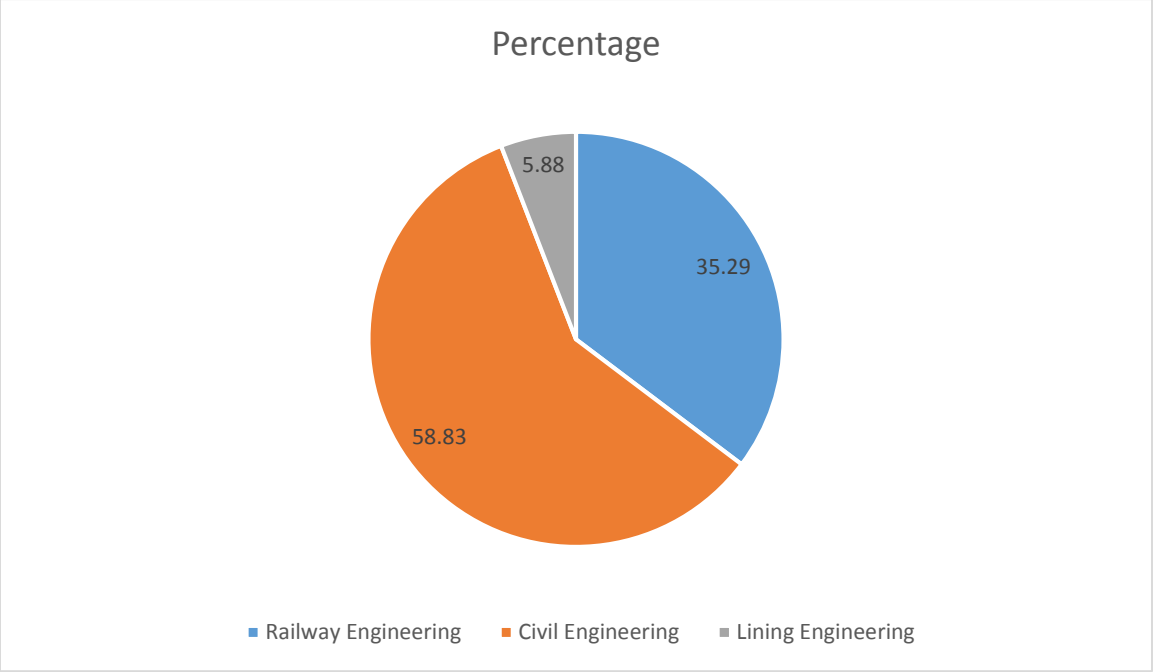


Fig 4.4: Field of specialization of respondents

The result in the above figure indicates that most of respondents (58.83%) are specialized in the field of Civil Engineering followed by Railway Engineering (35.29%) and 5.88% Lining Engineering.

In addition respondents were asked to identify their experience in the construction sector, railway sector, tunnel as general and tunnel in railway sector and the results are presented in table below.

Table 4.3 Work experience of respondents

Sector	Year of Experience		
	0 -5	6 – 10	More than 10
In the construction	11 (64.7%)	3 (17.65%)	3 (17.65%)
Railway	15 (88.24%)	0 (0%)	2 (11.76%)
Tunnel as general	16 (94.12%)	0 (0%)	1 (5.88%)
Railway tunneling	16 (94.12%)	0 (0%)	1 (5.88%)

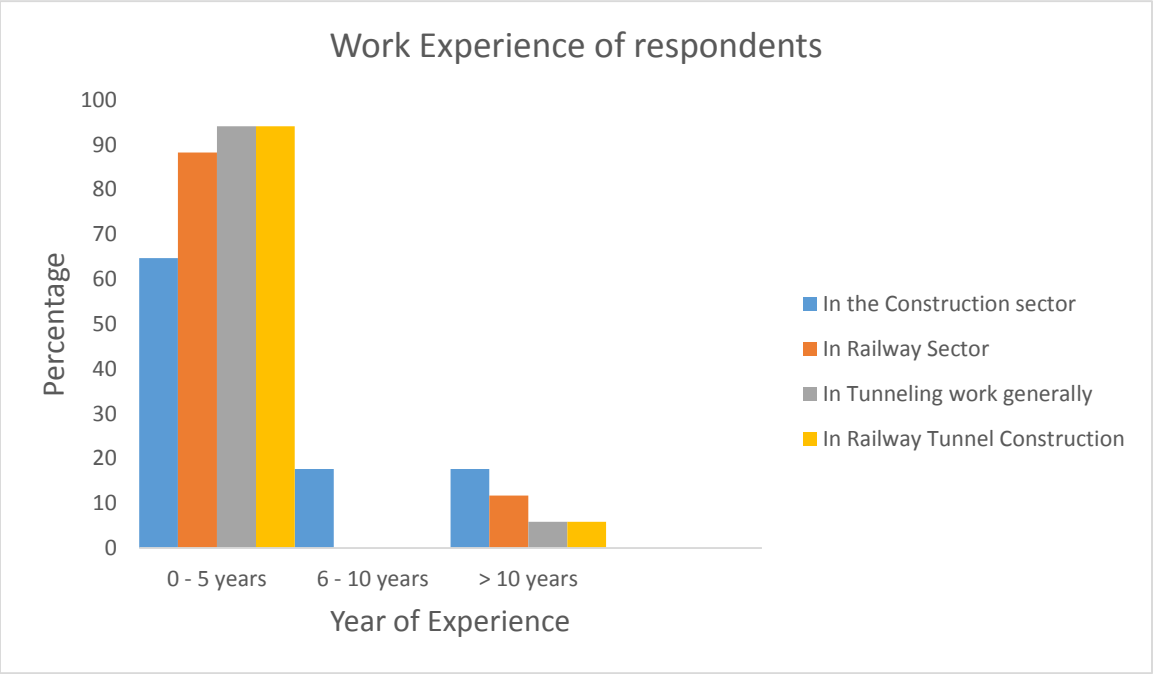


Fig 4.5: Work experience of respondents in the construction sector

The above table and figure shows that 64.7% (11) of the respondents have an experience in between 0 to 5 years in the construction sector, 17.65% (3) respondents experienced between 6 to 10 years, 17.65% (3) respondents have more than 10 year experience. Most of the respondents are less experienced, but they were designated from the beginning of the project up to the time of data surveying or they have been for about two years on the project which helps them to simply answer and give reliable information to the questions of the questionnaire.

4.3.2 Risk Sources or Causes of Construction Delay in Tunnels

A total of forty seven causes that contribute to tunnel construction project delays have been identified from the literature review. Therefore, the second and third objectives of the thesis are going to be assessed in this section by studying the frequency of occurrence and impact of the causes during tunnel construction.

The forty seven causes were categorized into eight major groups: Project related and contractual relationship, client related, contractor-related, consultant-related, labor-related, material-related, equipment-related, and external factors. Seventeen professionals working at Awash – Weldiya railway project tunnel department from client, contractor and consultant were successfully questioned to rate these causes based on frequency of occurrence and impact on time. Those professionals then rated the frequency of occurrence for each variable on an ordinal scale: high (3), medium (2), low (1) and impact on a scale from very high (5), high (4), medium (3), low (2), or very low (1). For each variable, the mean value of the respondents' frequency rating and impact rating were determined and named as frequency index and severity index respectively. Accordingly rank is given and the severity and frequency levels are identified using Table 4.4. Finally, the zone of each variable in the risk matrix was identified using Figure 4.6. A risk ranking matrix, as shown in the figure 4.6, can be used for categorizing the risk as minor, moderate or major and decide on the action to be taken. Minor risks can be accepted, moderate risks need some management measures and for major risks with high probability of occurrence and high impact a serious risk action schedule needs to be devised to manage the risk.

Table 4.4 Level of cause's severity and frequency

Index value (Scale)	Severity	Frequency
≤ 20%	very low (VL)	very low (VL)
20% - 40%	low (L)	low (L)
40% - 60%	moderate (M)	moderate (M)
60% - 80%	high (H)	high (H)
80% - 100%	very high (VH)	very high (VH

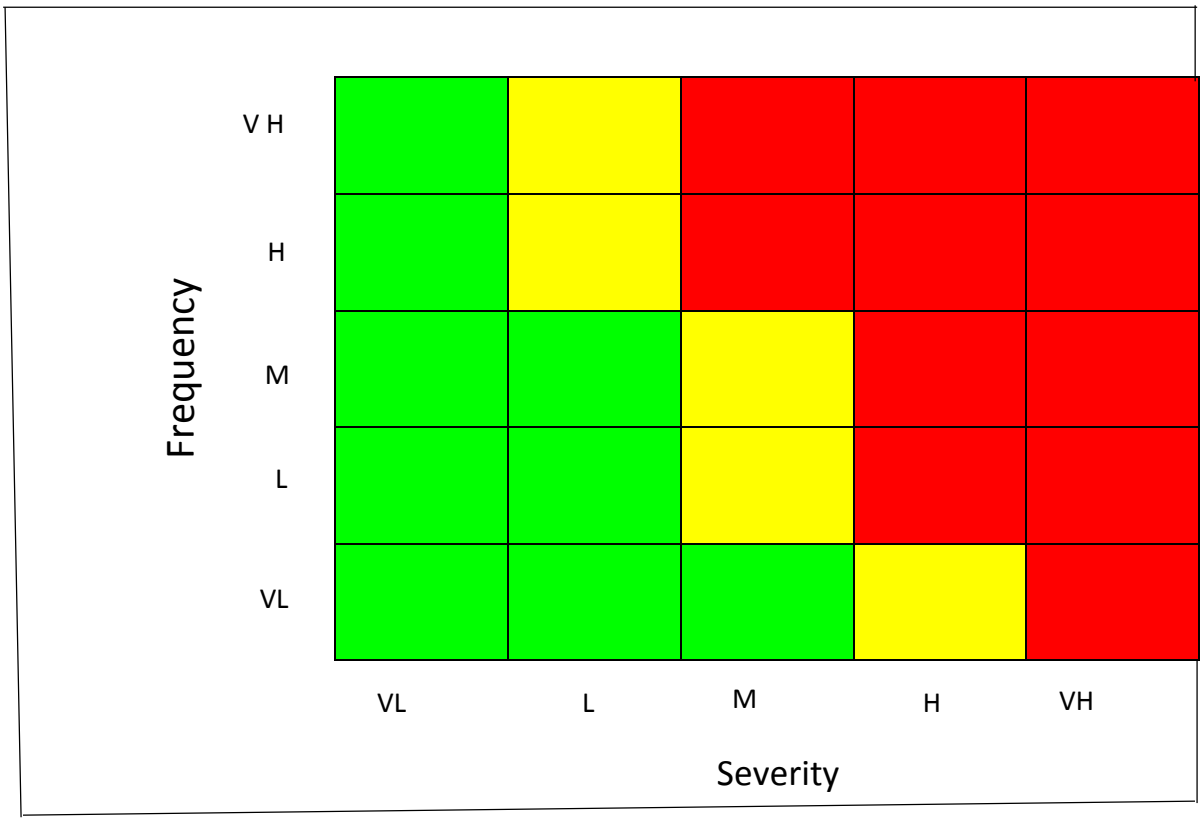


Fig 4.6: Risk matrix

The risk matrix includes three zones: red, yellow, and green; such that:

1) Green zone: risks in this zone are low level, and can be ignored. They had no/very less impact during construction of phase one tunnels of Awash-Weldiya railway project.

2) Yellow zone: risk sources in this zone are of moderate importance, and should be controlled. These risk sources had moderate impact during the construction of the tunnels in the case study.

3) Red zone: risks in this zone are of critical importance which means they had high negative impact on completion on time of phase one tunnels of Awash-Weldiya railway project. These are the top priorities, and close attention should be paid to them.

There may be dissimilarities in the ranking order of frequency occurrence and severity effect by overall. It means that not necessarily the more the causes frequently happens, the more it contribute severe impacts to the project. Therefore, it is essential to consider both frequency of occurrence and the severity effect of the causes into construction project. Derivation of importance index is important as they can point out the significant causes that contribute to project time overrun. Consequently, the suggestion of corrective action in minimizing project delays can be established based on these significant causes. The rationale for the importance index is that the importance of a cause of a delay is the result of the combined effect of the frequency and severity of the factor. Thus, two delay factors with the same frequency of occurrence would have the same importance if they have the same scores for the severity of their impact, but if one of the causes has a more severe impact, then it would be considered more important. The following is the brief description and discussion of these causes according to their groups and overall the forty seven factors which highlighted under the sub topic of impact on time.

$$FI = \sum_{1}^{3} \left(\frac{ni * fi}{A * N} \right) * 100$$

$$SI = \sum_{1}^{5} \left(\frac{ni * si}{A * N} \right) * 100$$

$$Imp.I = F.I * S.I$$

Where, F.I = frequency index, S.I = severity index, Imp.I = importance index, f_i = frequency weight given to each factor by respondents (low = 1, medium = 2, high = 3), s_i = severities/weight of the impact given to each factor by respondents (very low = 1, low = 2, moderate = 3, high = 4, and very high = 5), n_i = number of responses for each frequency weight and severity impact, A = the highest weight which is 3 for frequency and 5 for severity of impact, and N = the total number of responses.

4.3.3 Impact on Time

In this sub – topic details of risk sources in each group, the eight groups, and overall the forty seven causes/risk sources will be assessed according to their frequency of index, severity of impact on time, importance index and zone of each cause on the risk matrix. Finally top/key schedule risk sources and the impact of the risk sources on the objective of the project (completion with in scheduled time) will be determined.

4.3.3.1 Project related and contractual relationship factors

There are ten causes related to Project related and contractual relationship that were identified and ranked from the viewpoint of respondents. Table 4.5 shows the results of survey analysis on the causes of this category. These causes were ranked based on frequency**,** severity**,** and importance indices.

Table 4.5 Results of project related and contractual relationship factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Short contract duration	43.14	8	49.41	6	21.32	8
Legal disputes	52.94	4	49.41	6	26.16	4
Type of contract	45.10	7	57.65	4	26.00	5
Type of bidding	49.02	5	52.94	5	25.95	6
Change orders	62.75	1	60.00	3	37.65	2
Lack of constructability	39.22	10	45.88	9	17.99	9
Lack of Communication	47.06	6	48.24	8	22.70	7
Inaccurate quantity take – off	41.18	9	42.35	10	17.44	10
Rock and soil suitability	60.78	2	61.18	2	37.19	3
Project location	58.86	3	67.06	1	39.47	1

According to table 4.5 ‘change orders’ was ranked as the most frequent factor from its group. This is followed by ‘rock and soil suitability’ and ‘project location’. In term of its severity of effect to the time of tunnel construction, ‘project location’, rock and soil suitability’, and ‘change orders’ are the first, second and third top sever factors respectively. Therefore, the 3 most important causes in this group were project location, change orders, and rock and soil suitability respectively.

4.3.3.2 Client related factors

Six client related factors were identified and their survey results and rank are summarized in table 4.6 as follows.

Table 4.6 Results of client related factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Delays in payment from client	62.75	2	70.59	1	44.30	2
Difficulty in financing project/ Funding Problems	60.78	3	61.18	3	37.19	3
Delay in obtaining permits	47.06	5	60.00	4	28.24	4
Additional work	45.10	6	60.00	4	27.06	6
Client Knowledge	56.86	4	49.41	6	28.09	5
Land Acquisition Costs and right of way problems	78.43	1	64.71	2	50.75	1

As table 4.6 shows, 'Land Acquisition Costs and right of way problems' is the most frequent from client related factors. But, in case of impact on time it is on the second place followed to 'Delays in payment from client'. Land Acquisition Costs, Delays in payment from client, and Difficulty in financing project are the three most important causes from Client related factors.

4.3.3.3 Contractor related factors

There are six causes of contractor related delays that had been ranked in tunnel construction at Awash – Weldiya railway project as shown in table 4.7 below.

Table 4.7 Results of contractor related factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Rework due to errors	50.98	1	60.00	1	30.59	1
Disputes on site	50.98	1	40.00	6	20.39	6
Ineffective planning	49.02	3	52.94	5	25.95	4
Mistakes in design documents	43.14	6	54.12	4	23.35	5
Inadequate experience	45.10	5	60.00	1	27.06	3
Major and minor accidents during execution	49.02	3	56.47	3	27.68	2

Among the causes in this group 'Rework due to errors' and 'Disputes on site' are the frequent causes in tunnel construction at Awash – Weldiya railway project. However, 'Disputes on site' brings less severe impact to the project which is ranked sixth, whereas 'rework due to errors' has high severe impact and shares the first rank with 'inadequate experience'. Based on importance index 'rework due to errors' is in the first rank followed by Major and minor accidents during execution.

4.3.3.4 Consultant related factors

Table 4.8 represents the results of survey analysis of perception of respondents on consultant related factors which are three in number.

Table 4.8 Results of consultant related factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Late in approving documents	62.75	1	67.06	1	42.08	1
Poor coordination/ Poor Project Management	43.14	2	51.76	2	22.33	2
Poor quality control	39.22	3	48.24	3	18.92	3

Table 4.8 indicates that 'Late in approving documents', 'Poor coordination/ Poor Project Management', and 'Poor quality control' are the consultant related causes and ranked similarly in all frequency, severity, and importance from first to third respectively.

4.3.3.5 Labor related factors

Six labor related factors were identified from literature review and the respondent response analysis result is summarized in table 4.9 as follows.

Table 4.9 Result of labor related factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Labor shortage	35.29	6	42.35	5	14.95	5
Unqualified workforce/ Shortage of technical personnel (skilled labor)	45.10	2	50.59	3	22.82	2
Low productivity level of labors	47.06	1	52.94	2	24.91	1
Labor agitation and strikes	41.18	4	54.12	1	22.29	3
High cost of labor	39.22	5	36.47	6	14.30	6
Labor Absenteeism	43.14	3	45.88	4	19.79	4

According to table 4.9 'Low productivity level of labors' is the most frequent cause/factor followed by 'Unqualified workforce'. On the other hand 'Labor agitation and strikes' and 'Low productivity level of labors' are the causes with high severity. Considering both frequency and severity indices Low productivity level of labors, unqualified workforce, and Labor agitation and strikes are ranked from first to third respectively.

4.3.3.6 Material related factors

The table below shows the results of material related factors that ranked based on their frequency of index and severity of index.

Table 4.10 Results of material related factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Material shortage	52.94	2	55.29	3	29.27	3
Delay in delivery of materials	58.82	1	57.65	2	33.91	1
Damage of materials	50.98	4	47.06	4	23.99	4
Late procurement of materials	52.94	2	60.00	1	31.76	2
Unreliable sources of local & imported materials	41.18	5	42.35	5	17.44	5

As described in the above table, ranking of frequency index in material related factors was led by 'Delay in delivery of materials', followed by 'Material shortage' and 'late procurement of materials'. In ranking according to severity index 'Late procurement of materials' takes the first place, 'Delay in delivery of materials' and 'Material shortage' are the second and third respectively. In terms of importance Delay in delivery of materials gets highest rank followed by late procurement of materials.

4.3.3.7 Equipment related factors

Similar to the previous groups the causes in this group were also analyzed in a similar way and the result is shown in table 4.11.

Table 4.11 Results of equipment related factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Equipment breakdown and maintenance problem	56.86	1	60.00	1	34.12	1
Shortage of equipment	54.90	2	58.82	3	32.29	2
Low productivity of equipment	47.06	3	60.00	1	28.24	3

Equipment breakdown and maintenance problem was ranked first in frequency index, but it has equal severity weight of impact on time with Low productivity of equipment. As a result, Equipment breakdown and maintenance problem is the most important cause from a group of Equipment related factors.

4.3.3.8 External factors

There are eight external factors that were identified and ranked from the view point of respondents. Table 4.12 highlights the responses of survey expressed in frequency, severity and the importance indices for the external factors.

Table 4.12 Results of external factors

Risk Sources or Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Inflation/Relative Price Changes	45.10	4	44.71	6	20.16	5
Weather issues/ Bad weather	47.06	3	52.94	2	24.91	2
Traffic restriction	45.10	4	51.76	3	23.34	4
Unavailability of utilities	43.14	6	43.53	7	18.78	6
Force Majeure risks like flood, fire earthquake etc.	33.33	8	51.76	3	17.25	7
Unexpected Ground Conditions	56.86	1	58.82	1	33.45	1
Exchange Rate	43.14	6	36.47	8	15.73	8
Social and cultural impacts	52.94	2	47.06	5	24.91	2

It can be seen that ‘Unexpected Ground Conditions’ is exist frequently followed by ‘Social and cultural impacts’ and ‘Bad weather’. Likewise ‘Unexpected Ground Conditions’ is ranked first with high severity impact on time. This is followed by ‘Bad weather’, Traffic restriction and Force Majeure risks like flood, fire earthquake etc.

It is shown that 'Social and cultural impacts' is frequently occurred, but its impact on time is less (ranked 5). According to importance index Unexpected Ground Conditions, Bad weather, and Social and cultural impacts are the top cause in this group.

4.3.3.9 Ranking of the Groups

In a simple way averaging of the values of the causes in each group was determined, then ranking is performed and result is shown in table 4.13.

Table 4.13 Result of group of causes

Group of Causes	F.I	Rank	S.I	Rank	Imp.I	Rank
Project related and contractual relationship	50.01	4	53.41	5	26.71	5
Client related factors	58.50	1	60.98	1	35.67	1
Contractor related factors	48.04	6	53.92	4	25.90	6
Consultant related factors	48.37	5	55.69	3	26.94	4
Labor related factors	41.83	8	47.06	8	19.68	8
Material related factors	51.37	3	52.47	6	26.95	3
Equipment related factors	52.94	2	59.61	2	31.56	2
External factors	45.83	7	48.38	7	22.17	7

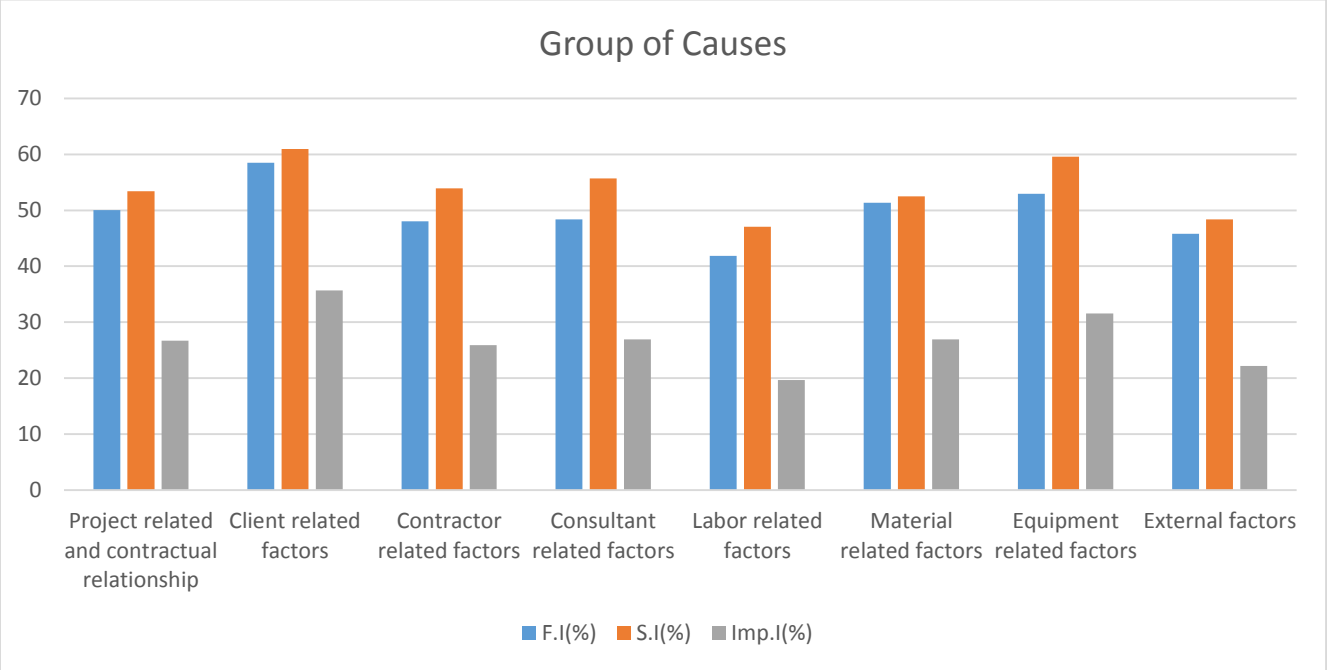


Fig 4.7: Chart of indices of group of causes

As indicated in table 4.13 above 'Client related factors' is the group which was frequently occurred and had high severity impact on the tunnel construction schedule of Awash – Weldiya railway project. The first reason was slow advancement of land acquisition and right of way problems related with access road that crosses farm lands; and entrance, exit and portal works resting on the farm lands. Another cause that play great role in client related groups was financial flow problems. The group ranked in the second based on frequency index, severity index and importance index is 'Equipment related factors'. The third frequent group was 'Material related factors', but the third severe group related to impact on time was 'Consultant related factors'. According to importance index or including frequency index and severity index the group 'Material related factors' was third followed to 'Equipment related factors'.

4.3.3.10 Ranking of all Causes

To identify the top causes of schedule delay, all the causes were ranked based on their frequency of occurrence, severity of impact and their zone. The result is presented in table 4.14 as follows.

Table 4.14 Result of all causes with impact on time

Risk Sources	F.I	Rank	S.I	Rank	Imp.I	Rank
Short contract duration	43.14	34	49.41	31	21.31	35
Legal disputes	52.94	13	49.41	31	26.16	21
Type of contract	45.10	28	57.65	17	26.00	22
Type of bidding	49.02	20	52.94	23	25.95	23
Delays in payment from client	62.75	2	70.59	1	44.29	2
Change orders	62.75	2	60.00	7	37.65	5
Late in approving documents	62.75	2	67.06	2	42.08	3
Poor coordination/ Poor Project Management	43.14	35	51.76	27	22.33	33
Difficulty in financing project/ Funding Problems	60.78	5	61.18	5	37.19	6
Rework due to errors	50.98	17	60.00	7	30.59	13
disputes on site	50.98	17	40.00	45	20.39	36
Ineffective planning	49.02	20	52.94	23	25.95	23
Mistakes in design documents	43.14	35	54.12	21	23.34	29
Lack of constructability	39.22	43	45.88	38	17.99	41
Inadequate experience	45.10	28	60.00	7	27.06	19
Labor shortage	35.29	46	42.35	42	14.95	46
Unqualified workforce/ Shortage of technical personnel (skilled labor)	45.10	28	50.59	30	22.81	31

Low productivity level of labors	47.06	23	52.94	23	24.91	25
Labor agitation and strikes	41.18	40	54.12	21	22.28	34
High cost of labor	39.22	43	36.47	46	14.30	47
Labor Absenteeism	43.14	35	45.88	38	19.79	38
Material shortage	52.94	13	55.29	20	29.27	14
Delay in delivery of materials	58.82	7	57.65	17	33.91	9
Damage of materials	50.98	17	47.06	36	23.99	28
Late procurement of materials	52.94	13	60.00	7	31.76	12
unreliable sources of local & Imported materials	41.18	40	42.35	42	17.44	42
Inflation/Relative Price Changes	45.10	28	44.71	40	20.16	37
Equipment breakdown and maintenance problem	56.86	8	60.00	7	34.12	8
Shortage of equipment	54.90	12	58.82	15	32.30	11
Low productivity of equipment	47.06	23	60.00	7	28.24	15
Delay in obtaining permits	47.06	23	60.00	7	28.24	15
Weather issues/ Bad weather	47.06	23	52.94	23	24.91	25
Major and minor accidents during execution	49.02	20	56.47	19	27.68	18
Traffic restriction	45.10	28	51.76	27	23.34	29
Unavailability of utilities	43.14	35	43.53	41	18.78	40
Force Majeure risks like flood, fire earthquake etc.	33.33	47	51.76	27	17.25	44
Additional work	45.10	28	60.00	7	27.06	19
Unexpected Ground Conditions	56.86	8	58.82	15	33.45	10
Exchange Rate	43.14	35	36.47	46	15.73	45
Client Knowledge	56.86	8	49.41	31	28.10	17
Land Acquisition Costs and right of way problems	78.43	1	64.71	4	50.75	1
Poor quality control	39.22	43	48.24	34	18.92	39
Lack of Communication	47.06	23	48.24	34	22.70	32
inaccurate quantity take – off	41.18	40	42.35	42	17.44	42
Rock and soil suitability	60.78	5	61.18	5	37.19	6
project location	56.86	8	67.06	2	38.13	4
social and cultural impacts	52.94	13	47.06	36	24.91	27

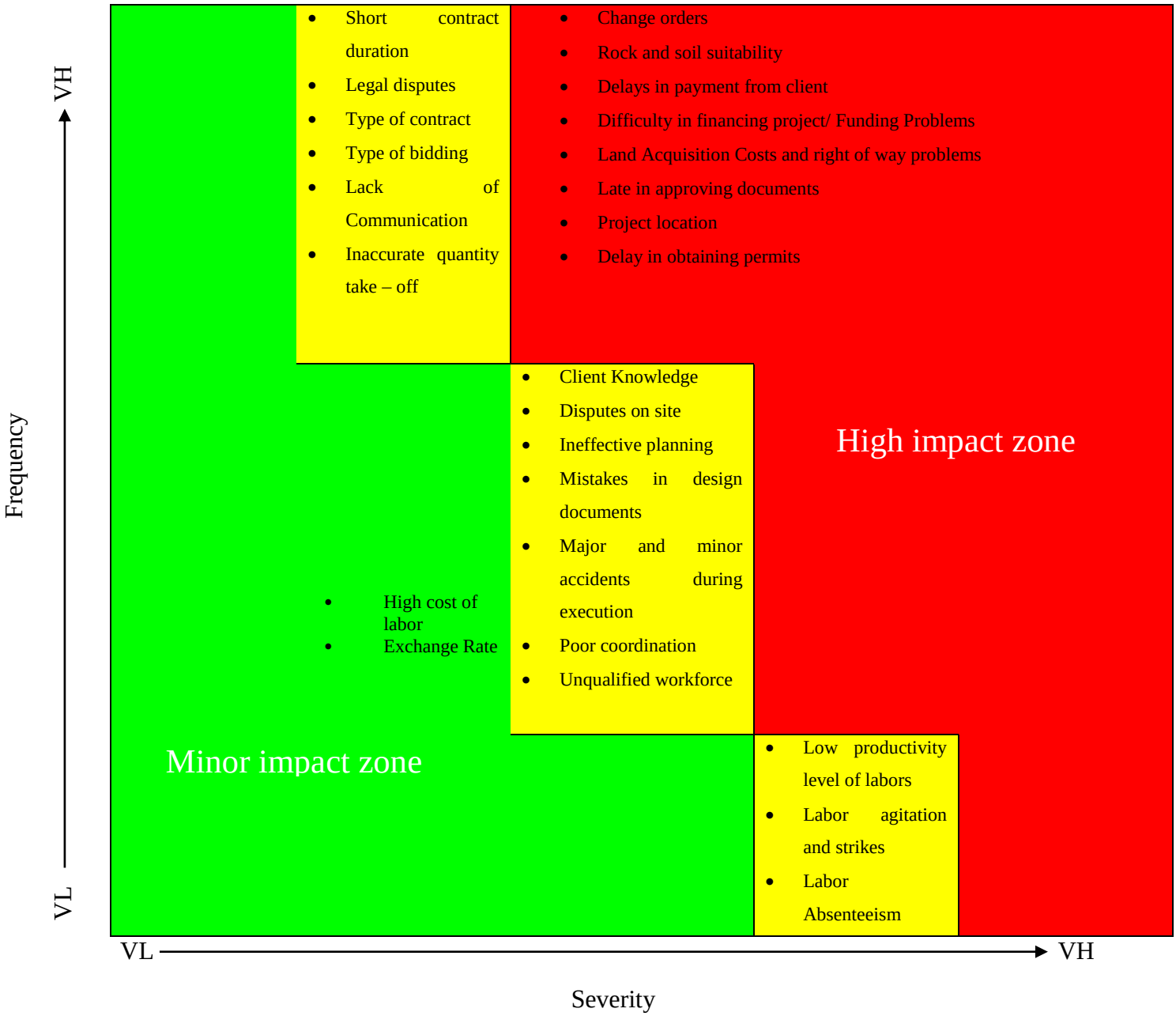
As table 4.14 shows, the sixteen most frequent causes of tunnel construction delay were identified as Land Acquisition Costs and right of way problems, Delays in payment from client, Change orders, Late in approving documents, Difficulty in financing project/ Funding Problems, Rock and soil suitability, Delay in delivery of materials, Equipment breakdown and maintenance problem,

Unexpected Ground Conditions, Client Knowledge, project location, Shortage of equipment, Legal disputes, Material shortage, Late procurement of materials, and social and cultural impacts.

The sixteen factors that were ranked the most severe in terms of their impact on tunnel construction delay were Delays in payment from client, Late in approving documents, project location, Land Acquisition Costs and right of way problems, Difficulty in financing project, Rock and soil suitability, Change orders, Rework due to errors, Inadequate experience, Late procurement of materials, Equipment breakdown and maintenance problem, Low productivity of equipment, Delay in obtaining permits, Additional work, Shortage of equipment, and Unexpected Ground Conditions.

Considering both frequency and severity indices the ten most important or key causes of delay were identified as; Land Acquisition Costs and right of way problems, Delays in payment from client, Late in approving documents, project location, Change orders, Difficulty in financing project, Rock and soil suitability, Equipment breakdown and maintenance problem, Delay in delivery of materials, and Unexpected Ground Conditions.

By using the risk matrix represented in previous section 4.3.2, all the 47 causes can be categorized in to three zones which are indicated by red, yellow and green colors. The causes in the red zone are marked as causes with high negative impact on the tunnel construction schedule of the project. The risk sources/causes located in the middle of the matrix (yellow zone) are classified as a moderate level where the risks should be concerned, but not as extreme as the most negative risks. On the other hand causes on the green zone are categorized as causes with less influence (minor impact) on the tunnel construction schedule of the project. The result of the analysis is shown in figure 4.8 as follows:



The causes in the red zone had high negative impact in the construction time of phase one tunnels of Awash-Weldiya railway project. Consequently, these causes should took priority during application of measurements.

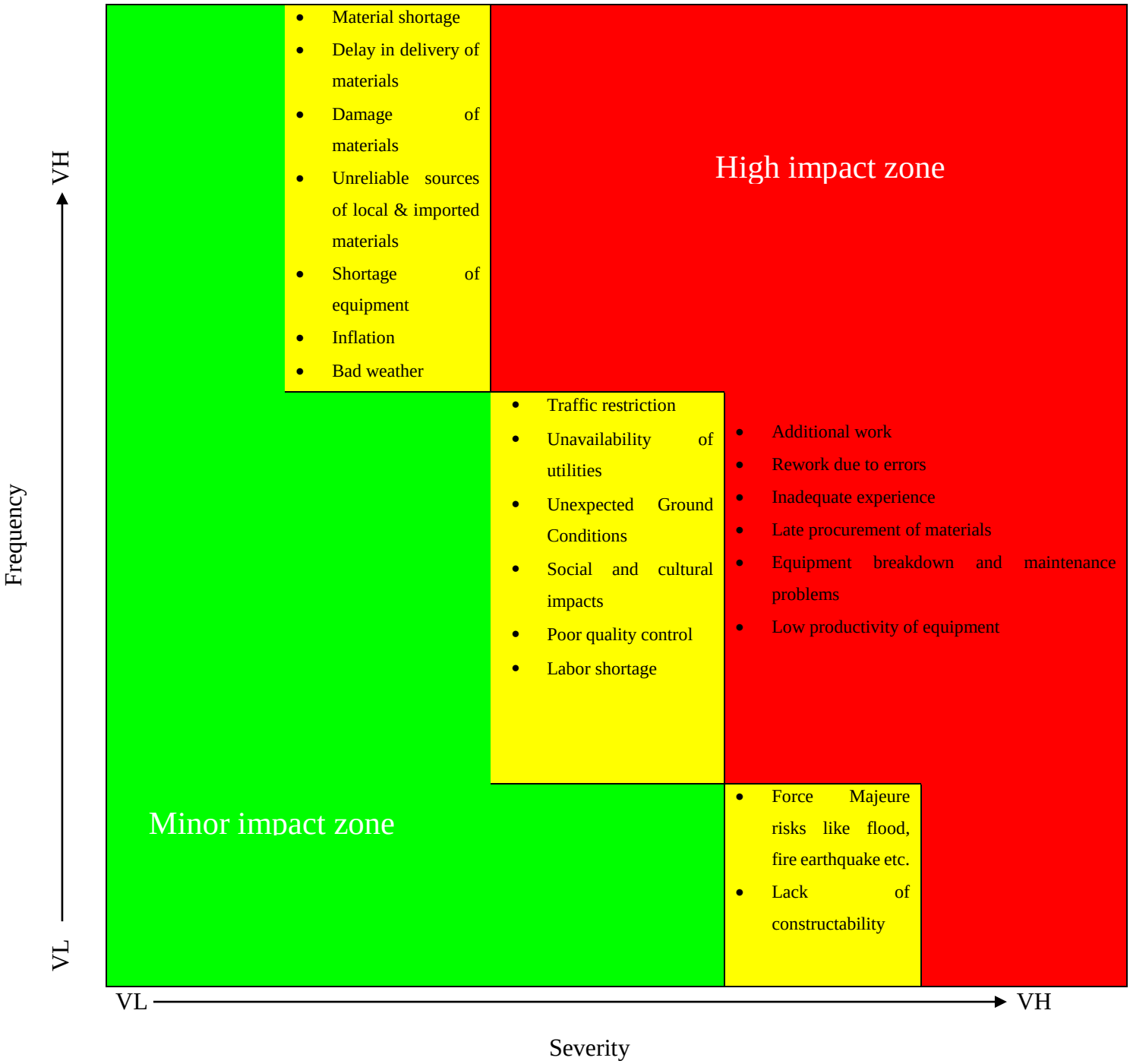


Fig 4.8: Impact zone of each causes

The above risk matrix figure shows that 14 causes had high impact, 31 causes had moderate impact, and 2 causes had minor impact on the construction time of phase one tunnels of Awash – Weldiya railway project.

4.3.4 Problems Faced

The problems occurred during construction of the tunnels in the case study were identified by professionals on the questionnaire and summarized from weekly and monthly reports of September 2015 to January 2017. The main problems which led to construction delay in the constructed tunnels are listed and described as follows:

4.3.4.1 Right of way problems

Reports and response of professionals shows that right of way is one of the main problems of the project. In tunneling work access road to the site of the tunnels, portal works and entrance and exit main routes are the activities that are directly affected by right of way issues. If the right of way issue is not early compensated, the activities of the tunnel are halted by the local people and may take long time to solve the problem and resume the activities. Therefore, right of way problem directly influences the construction schedule of the tunnels. This can be supported with the following figure of T_6 on which the activities was halted for about one month due to right of way issues.



Fig 4.9: Work activities halted due to right of way problems (Weekly progress reports, March 2016).

The author believes that, this can be minimized by solving the issue during pre-construction phase, allow participation of the local people and supporting of the surroundings.

4.3.4.2 Flooding problems

Flood problem due to heavy rain around the portals is another problem that was described by professionals and listed on the weekly and monthly reports of the project. As shown in the figure below the problem was severe in T_5 and activities were stopped for about more than one month. Hence, flooding problem directly affects the construction schedule of the tunnels. The problem was solved by preparing flood protecting canals and drainages. But, preparing of the canals and drainages needs additional time which has its own impact on the construction schedule of the tunnel.

In order to avoid this problem flood diversion and protecting works should be included in the design of the tunnels and should be provided before the construction of the tunnels.

The following figures shows the flood problems that occurred during construction of the tunnels.



Fig 4.10: Reoccurring flooding problem due to heavy rain (Weekly progress reports, April and May 2016).

4.3.4.3 Quality problems

Quality is another challenging issue which requires a close monitoring of the activities. Quality problems like; Segregation, Not adequate concrete cover in final lining of some tunnels, Poor drainage channel at some portals, concrete breakage around the rusted fence, Shotcrete piece fallen (adhesion problem), and observance of white spots on the casted concrete are some of the quality problems that seen during construction of the tunnels under the case study. The following figures taken from reports of the project helps to visualize some of the quality problems:







Fig 4.11: Some of quality related problems (Weekly progress reports, from September 2015 to June 2016)

The consultant side professionals recommended that some of the above quality problems may be created due to not respecting of the mix design and shotcrete formula. In addition they recommend to contractor:

- To start immediate investigation to find if problem is in the concrete plant or discrepancies in the concrete spray machine.
- To test concrete on plant before loading to mixer and on site before concreting.
- To use smaller size aggregates in order to achieve finer surface to easy facilitate waterproofing application (To arrange the aggregate size based on the roughness of the surface).
- To investigate the geology horizontally.

Finally based on the above recommendations and his experience the contractor solved the quality problems. But the works with quality problems needs repairing works which takes additional time and obviously has an impact on construction schedule of the tunnels.

4.3.4.4 Health and Safety problems

Underground works are more exposed to health and safety problems than ground works. For example during construction of the tunnels in the case study Health and safety problems such as: unsafe lifting operation, dust problems, closed ventilation, unsafe conduct of workers on arch reinforcement works, unsafe working conditions due to exposed reinforcement bars, and working without safety instruments (like safety shoes, safety belts, etc) had observed. The figure below shows workers working without safety belts at heights and dust problems.



Fig 4.12: Employees were working without safety belts at heights (left) and Presence of dusty atmosphere (right) (Weekly progress reports, January 2016)

The occurrence of the above listed and other safety and health problems during construction activities decreases the output of the workers, and then influences the construction schedule.

Generally in addition to the above briefly discussed problems, there were a number of problems identified by tunnel professionals and listed on the report of the project and are summarized as follows:

Table 4.15 Actual problems faced in the case study

Soil movements around the portals solved with constructing bigger portals and adding support (increasing portal length and fill it with other material with compaction).	Variability of the soil behavior in a short distance (the rock mass requires close monitoring).
High ground water levels (Water seepage) solved with submerged pumps.	Lack of recent technologies to detect and examine occurrence of Geo-hazards.
Lack of state of art technology to detect Water table variations.	Poor soil conditions solved by providing umbrella supports.
Remoteness of the location of the design office.	Pending approval of Detailed Design Drawings.
Delay instrumentation and monitoring result.	Late Conclusion of the design.
Difficult ground conditions.	Equipment breakdowns.
Weather problems.	Late arrival of some equipment.
Soil instability.	Security problems at night works.
Delayed field test results.	Delay on relocation of utilities.
Unexpected geotechnical problems.	Unsuitable soil disposal land acquisition.

4.3.5 Measures Taken/Mitigation Actions

Respondents were also asked to give a type of mitigation action that can be used in tunnel construction, and their answers are listed as follows:

Table 4.16 Recommended measures

Staying within the scope of project's plans regardless of Client's, Contractor's need to add new features outside the scope and aims of the project.	Smooth communication between the three parties in the construction (i.e. easily reaching into consensuses).
Allow their participation and support the plan of the activities of the surrounding community.	Improving project management (Use good project coordination and management system).
Clear and concise project planning and re-planning during construction.	Giving immediate solutions to the problems happened in the site.
Change of alignment design based on soil investigation.	Providing support design according to new RMR value.
Strict supervisions of construction sites.	Use good scheduling tools & charts.
Use regulation.	Training of the man power.
Solving project funding problems.	Solving contractual problems.
Solving project facilitation problems.	Solving design department problems.
Detail/deep geotechnical investigation.	Solid design
Use adequate equipment.	Use experienced crews.
Safe procedures implement.	Improving safety and health.
Considering environmental issues.	Continuous assessment.
Knowledge transfer.	Pre preparing of tunnel construction area.
Paying land acquisition costs on time.	Delivery of materials on time.
Solving right of way issues in advance.	

4.4 Validation of Questionnaire Results

Even though, getting claim related data of the project is very difficult, some not settled claims from the project are used to validate or to check the results of the questionnaire. Claim for delay on access to construction site and prevention of the execution of works by local people plus land acquisition costs for tunnel site mobile camp, dump area, entrance and exit main route, and exit and entrance portal works is one of the ongoing claims on the case study project. This claim was represented as Land Acquisition Costs and right of way problems from the listed risk sources of construction time on the questionnaire. Considering both frequency and severity indices of the responses of respondents this risk source was ranked as first cause of construction delay during the construction of phase one tunnels of Awash-Weldiya railway project.

Claim for delay on documents and drawings approval and employer's instruction not to proceed with detailed design works due to pending consultant's review of documents and drawings is another ongoing claim on the project. This claim is related with the risk source named on the questionnaire as late in approving documents. According to importance index late in approving documents was ranked as third cause of construction delay in phase one tunnels of Awash-Weldiya railway project.

Claim for failure to receive the value added tax of the project may related with risk sources on the questionnaire like delays in payment from client and/or difficulty in financing project. Based on importance index those risk sources were ranked as second and sixth respectively.

In addition to the above claims, placement of materials inconveniently and quality problems were registered as the main non conformity letters related to tunnels on the project. Similarly those issues were identified as problems faced during the construction of the tunnels by respondents on the questionnaire and are listed on weekly progress report of tunnel construction of the project.

The first claim was directly related with duty of the client, the second claim with consultant and client, and the third claim may be related with client and donors of the project. But, the non-conformity issues are directly related with the work of the contractor.

Chapter Five: Conclusions and Recommendations

5.1 Introduction

This chapter includes the conclusions and recommendations of the research, gained/sum up from and related to the previous chapters, which in turn tries to answer the research questions and accomplishes the research objectives. The research had three objectives which were to assess the extent of construction delay at Tunnels of Awash – Weldiya railway project, to identify the key causes of delay and problems encountered during the construction of the tunnels, and to rate the impact of the causes of delay on the construction time of the tunnels.

Archival documents were used to determine the extent of construction delay of phase one tunnels of Awash – Weldiya railway project. Literature review and discussion with professionals were also used to identify delay causes of tunnel construction. In addition questionnaire survey was used to find out the main causes of delay, to identify problems encountered and to rate the impact of the causes of delay on construction time. For the first objective delay in % was determined by deduction original duration from actual duration. In order to achieve the second and third objectives frequency of index, severity index, importance index and zone of each cause were determined according to the response of the respondents and risk matrix. Once these tunnel construction delay factors have been identified, suitable preemptive measures can also be put in place to counter the negative effects that may arise as a result of their occurrence.

The results of the questionnaire survey, archival documents and discussion of the findings were presented in the previous chapter. In this chapter the conclusions derived from the research findings and the recommendations are presented.

5.2 Conclusions

Based on the results of the analysis of archival documents and respondents' responses the following conclusions are drawn.

1. The first objective was to assess the extent of construction delay at Tunnels of Awash – Weldiya railway project. Four of the six tunnels had a construction delay with T_2 119.41%, T_3 12.84%, T_4 19.21%, and T_7 102.29%. The remaining two tunnels were accomplished before the final date of the schedule with T_5 0.94% and T_6 20% underrun. The reduction of delay in tunnels 3 and 4, and avoiding delay in tunnels 5 and 6 was mainly due to: advance the construction in both entrance and exit sides, execute with additional crews, and additionally working with night shifts plus in some part of the tunnels the support class was A3 and not require final concrete lining. The delay existed in tunnel 2 was due to execution only in one side and change of support class from A3 in to A4, thus requires inner concrete lining which takes more time than that of shotcrete support in A3 support class. The reasons of delay in tunnel 7 were advancing only in one side and quality problems. To finalize the phase one tunnels of Awash – Weldiya railway project had an average delay of 38.8%.

2. The second objective was to identify the key causes of delay and problems encountered during the construction of the tunnels. Considering both frequency and severity of impact, the result from analysis shows that the top ten causes of delay in tunnel construction were Land Acquisition Costs and right of way problems, Delays in payment from client, Late in approving documents, project location, Change orders, Difficulty in financing project, Rock and soil suitability, Equipment breakdown and maintenance problem, Delay in delivery of materials, and Unexpected Ground Conditions. Here the main problems were also identified as right of way problems, flooding problems, quality problems, and health and safety problems.

3. The third objective was to rate the impact of the causes of delay on the construction time of the tunnels. This objective was addressed by using a risk matrix which includes the value of frequency index and severity index. The risk matrix is represented by three colors of red, yellow, and green. The causes in the red zone are marked as causes with high negative impact on the tunnel construction schedule of the project. Fourteen causes namely Delays in payment from client, Change orders, Late in approving documents, Difficulty in financing project/ Funding Problems, Rework due to errors, Inadequate experience, Late procurement of materials, Equipment breakdown and maintenance problem, Low productivity of equipment, Delay in obtaining permits, Additional work, Land Acquisition Costs and right of way problems, Rock and soil suitability, and project location were determined as located on the red zone in the risk matrix. On the other hand causes on the green zone are categorized as causes with less influence (minor impact) on the tunnel construction schedule of the project. The causes on the green zone are two and described as High cost of labor, and Exchange Rate. The remaining 31 schedule risk sources are located in the middle of the matrix (yellow zone) and are classified as a moderate level where the risks should be concerned, but not as extreme as the most negative risks. To conclude, 14 causes had high impact, 31 causes had moderate impact, and 2 causes had minor impact on the construction time of phase one tunnels of Awash – Weldiya railway project.

5.3 Recommendations

The following recommendations are raised in order to minimize delays and facilitate similar future works.

1. Right of way problem was one of the key schedule risk sources. Therefore, client should give an attention on the right of way problem in future tunnel construction projects. Before the construction starts, client is recommended to fulfill all the necessary requirements for delivering the site.

2. Delays in payment from client and funding problems are among the key schedule risk sources and are interrelated to each other. Hence, it is advised that, appropriate funding levels should always be determined at the planning stage of the project so that regular payment should be paid to contractors for work done in order to keep the flow of the work.

3. Railway Tunnels are sensitive to geological variations, seismic loads and Geo-hazards. Ignorance and any change of those conditions may lead the construction time of the tunnels to take longer than expected. Therefore, very thorough studies and site investigations during the preconstruction phase and modernized project planning, re-planning tools has to be applied for on time or in time completion by minimizing the delay of railway tunnel projects. During the construction time of tunnel horizontal geology probing is also required in order to discover actual rock nature and to implement proper rock support.

4. Tunnel construction totally related with geotechnical knowledge. In order to reach time targets of tunnel construction the drilling works, geophysical maps, surveying controls, and other sequential activities should be made precisely.

5. The tunnels being executed in the Awash–Weldiya/Haragebeya railway project follows the NATM construction methodology, commonly used all around the world. This methodology uses different types of equipment. Selection of the suitable equipment should be based on the geological and geotechnical reports and should be identified in the contract briefly since equipment break down and maintenance problem was one of the key schedule

risk sources. Critical equipment contingency planning is also needed for timely repair and return service after a breakdown.

6. The contractor in the case study project applies different means like working with night shifts to reach the targeted construction time. Here, the author wants to advise to whom may be concerned to closely control the quality of the works as the author believes fasting the activities and changing any conditions may decrease the quality of the works unless otherwise properly implicated.

7. In order for researchers to come up with very useful findings, it is recommended that parties involved in the construction industry be more cooperative by willingly participating and giving any support needed for the research. In fact, it is not easy to get any data especially from foreigner contractors. Therefore, Government and Client should give an intensive way of sharing of data during the time of contract of any new project.

8. Knowledge transfer and experience sharing from the experienced foreigner contractors to local man power is mandatory and should be performed in a continuous and series manner. This helps in getting of experienced crews in future similar works and has its own role in minimization of delays. Involvement of local sub-contractors should also be encouraged.

9. This research was limited to phase one tunnels of Awash-Weldiya railway project. Having limitation of data in mind, next researchers can include all tunnels such as phase two tunnels in the project and other tunnels which are previously constructed and currently under-construction in different projects in the country.

10. The findings in this research could help the practitioners in tunnel construction to gain better understanding about the problems, and causes of delay at the construction stage. By taking care of these potential causes and applying the mitigation actions that described in section 4.3.5 in their present and future projects, construction participants can reduce and control the extent of delays.

5.4 Suggestions for Future Works

1. Assessment of delay minimization techniques in tunnel construction.
2. Assessment of tunnel construction time estimate.
3. Claim management in tunnel construction.

References

Abubeker Jemal Mustefa, (2015), 'Factors Affecting Time and Cost Overrun in Road Construction Projects in Addis Ababa', Master's thesis, Addis Ababa university, Addis Ababa, Ethiopia.

Ahmed Senouci, Alaa Ismail, and Neil Eldin, (2016), 'Time Delay and Cost Overrun in Qatari Public Construction Projects', Creative Construction Conference, Procedia Engineering 164, June 25-28 pp. 368-375.

Amani Suliman BU-Qammaz, (2007), 'risk assessment of international construction projects using the analytic network process' Master's Thesis, Middle East Technical University, Turk.

Ashwini Arun Salunkhe, and Rahul S. Patil, (2014), 'Effect of Construction Delays on Project Time Overrun: Indian Scenario', International Journal of Research in Engineering and Technology, Volume: 03 Issue: 01, pp 543-547.

Asish Ram and Pratheeba Paul, (2015), 'Study on Construction Sequence Delay for Road Infrastructure Projects', IOSR Journal of Mechanical and Civil Engineering, Volume 12, Issue 2 Ver. VI, pp 15-21.

Bikram Nepal, (2014), 'Time Management in Projects: Tools, Techniques and Methods', Specialization Project, Norwegian University of Science and Technology, Department of Production and Quality Engineering.

CECW-EG and CECW-ED, (1997), 'Tunnels and Shafts in Rock,' Manual No. 1110-2-2901, U.S. Army Corps of Engineers, Washington.

Christoph Sturm, (2011), 'Shallow tunnels and caverns in urban areas', Master's Thesis, Austria.

C. Jeremy Hung, James Monsees, Nasri Munfah, and John Wisniewski, (2009), 'Technical Manual for Design and Construction of Road Tunnels - Civil Elements', National high way Institute, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C, 702 pp.

Dayang Sabriah Binti Safri, (2009), 'A Comparative Study of Construction Project Delays in Johor and Sabah Region', Master's project, Faculty of Civil Engineering Universiti Teknologi Malaysia.

Debasis Sarkar, and Goutam Dutta, (2011), 'A Framework of Project Risk Management for the Underground Corridor Construction of Metro Rail', Indian Institute of Management Ahmedabad, India, working paper no 2011-02-05.

Dimitrios Kolymbas, (2005), 'tunneling and tunnel mechanics', Innsbruck, 431 pp.

Divya.R, and S.Ramya, (2015), 'Causes, Effects and Minimization of Delays in Construction Projects' International Journals, National Conference on Research Advances in Communication, Computation, Electrical Science and Structures, pp 47-53.

Energy Department, (1985), 'Geological Complications and Cost Overruns: A Survey of Bank-Financed Hydroelectric Projects', International Bank for Reconstruction and Development, International Development Association, World Bank, Energy Department Note No. 61.

Erfan Hoseini, (2014, 'Time Thieves and Bottlenecks in Projects', Master's project, Norwegian University of Science and technology, Department of Production and Quality Engineering, NTNU-Trondheim, Norway.

Erik Nygårdsvoll, (2014), 'Application of water jet cutting for tunnel boring', Master's Thesis, Department of Industrial Economics, Risk Management and Urban Design, University of Stavanger, Norway.

Eva Greifeneder, (2003), 'Comparison of Cut-and-Cover Tunneling Method vs. New Austrian Tunneling Method (NATM) for Urban Tunnels with Shallow Overburden,' Master's Thesis, Technischen Universität Wien.

Ghazi Saad A Elawi, (2015), 'Owners' Perspective of Factors Contributing to Project Delay: Case Studies of Road and Bridge Projects in Saudi Arabia', Journal for the Advancement of Performance Information and Value, vol. 7 no. 1pp. 1-11.

Harold Kerzner, (2009), 'Project Management: A Systems Approach to Planning, Scheduling, and Controlling', Tenth Edition, The International Institute for Learning New York, New York.

Henry Alinaitwe, Ruth Apolot, and Dan Tindiwensi, (2013), 'Investigation into the Causes of Delays and Cost Overruns in Uganda's Public Sector Construction Projects', Journal of Construction in Developing Countries, 18(2), 33–47.

Hervé Landrin, Chris Blückert, Jean-Paul Perrin, Steve Stacey, and Alessandro Stolfa, (2006), 'Anticipated Loss of Profit/Delay in Start Up ("ALOP/DSU") coverage for tunneling risks?', The International Association of Engineering Insurers 39th Annual Conference, Boston, pp 1-85.

Ismaaini Binti Ismail, (2014), 'Risk Assessment of Time and Cost Overrun Factors throughout Construction Project Lifecycle', Master's thesis, Faculty of Civil and Environmental Engineering Universiti Tun Hussein Onn Malaysia.

Jessica Haire, (2014), 'Construction Schedule Delays', Fox Rothschild LLP, Washington DC, Federal publications.

Kim Heldman, PMP, (2005), 'Project Management Professional Study Guide 3rd edition', Wiley publishing, Inc., Hoboken, New Jersey.

K. L. Ravisankar, S. AnandaKumar, and V. Krishnamoorthy, (2014), 'Study on the Quantification of Delay Factors in Construction Industry', International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 1, pp 105-113.

Mauriya Vinod Kumar, Yadav Praveen Kumar, and Angra Vinod Kumar, (2010), 'Challenges and Strategies for Tunneling in the Himalayan Region', Indian Geotechnical Conference, NTPC Limited, Bilaspur, India, December 16-18, pp. 93-96.

Milad Foroughi Masouleh, (2015), 'Multi-Attrubited Selection of Excavation Methods in Tunneling Construction', Master's Thesis, Concordia University, Montreal, Quebec, Canada.

Muna Abebe, (2015), 'Evaluation of alternative Track Alignments on Whole Life Cost of Lot 11 Section of the Awash-Weldiya Railway Line', Master's thesis, Addis Ababa university, Addis Ababa, Ethiopia.

Musirikare Mihigo Amandin, and Julius Warren Kule, (2016), 'Project Delays on Cost Overrun Risks: A Study of Gasabo District Construction Projects Kigali, Rwanda', ABC Journal of Advanced Research, Volume 5, No 1, pp. 21-34.

Olga Špačková, (2012), 'Risk management of tunnel construction projects', Doctoral Thesis, Faculty of Civil Engineering, Department of Mechanics, Czech Technical University in Prague.

PMI, (2013), 'A guide to the project management body of knowledge (PMBOK guide).' Project Management Institute, Newtown Square, Pennsylvania, USA.

PMI, (2003), Construction Extension to A Guide to Project Management body of knowledge (PMBOK – 2000 Edition), Project Management Institute, Newton Square, Pennsylvania, USA.

Robel Assefa, (2014),'Schedule Delay Identification and Assessment on Addis Ababa's Light Rail Transit Construction Project', Master's Thesis, Addis Ababa university, Addis Ababa, Ethiopia.

Shaikh Asif Abdus Saeed, (2009), 'Delay to Projects – Cause, Effect and Measures to reduce/ Eliminate Delay by Mitigation / Acceleration', dissertation, The British University in Dubai, United Arab Emirates.

Shigeru Onoda, (2015), 'a history of railway tunnels in Japan', japan railway & transport review No 66, Japan.

Siraw Yenesew Tesfa, (2016), 'Analysis of Factors Contributing to Time Overruns on Road Construction Projects under Addis Ababa City Administration', International Journal of Science and Research, Volume 5 Issue 7 pp 2181- 2187.

Tadesse Ayalew, Zakaria Dakhli, and Zoubeir Lafhaj, (2016), 'Assessment on Performance and Challenges of Ethiopian Construction Industry', Quest Journals, Journal of Architecture and Civil Engineering, Volume 2 ~ Issue 11, pp. 01-11.

Tayachew Melisew, (2015), 'Design and Construction of Tunnels in Ethiopia: Lessons Learned from the Case of Gilgel Gibe III Hydropower Tunnels', Master's thesis, Addis Ababa university, Addis Ababa, Ethiopia.

Therese Isaksson, (2002), 'Model for estimation of time and cost based on risk evaluation applied on tunnel projects', Doctoral thesis, Royal Institute of Technology Stockholm, Sweden.

Zinabu Tebeje Zewdu, (2016), 'Construction Projects Delay and Their Antidotes: The Case of Ethiopian Construction Sector', International Journal of Business and Economics Research. Vol. 5, No. 4 pp. 113-122.

Appendices

Appendix A: Questionnaire Form

Part 1: Introduction

The following questionnaire is prepared to gather information from tunnel Professionals of client, contractor and consultant of Awash – Weldiya railway project. The information is required for an academic research entitled **"Assessment of potential causes of construction delay in Tunnels; A case study at Awash – Weldiya Railway Project"**. The outcome of the research will serve as partial fulfillment of MSc in Civil Engineering with Railway Stream. The main objectives of the research are:

1. To assess the time performance of tunneling work at Awash – Weldiya railway project.
2. To identify schedule risk sources of tunnel construction.
3. To identify key risk sources and problems encountered during tunnel construction.
4. To assess the impact of the risk sources on the construction time of the tunnels.
5. To recommend on the findings of the research and future works.

The questionnaire is categorized into two sections i.e:- respondent profile and risk sources & measures taken. Your response is highly valuable and contributory to the outcome of the research. All feedback will be kept strictly confidential, and utilized for this academic research only.

Thank you

Shambel Meressa
Post graduate student, Railway Engineering
Addis Ababa University Institute of Technology
Tel: +251 936566379
E-mail: sham6739@gmail.com
Addis Ababa, Ethiopia

Part 2: General Profile of the Respondent

1.1 Name (Optional): _____

1.2 Position: _____

1.3 Organization: _____

1.4Address: _____

1.5 Educational status?

□ BSc □ MSc □ PhD □ other; please specify: _____

1.6 What is your field of specialization?

□ Railway engineering □ civil engineering □ Electrical engineering

□ Mechanical engineering □ others, please specify: _____

1.7 How long have you worked in the Construction sector?

□ 0 – 5 years □ 6 – 10 years□ 11 – 15 years □ More than 15 years

1.8 How long have you been involved in railway construction projects?

□ 0 – 5 years □ 6 – 10 years □ More than 10 years

1.9 How long have you been involved in tunnel construction projects?

□ 0 – 5 years □ 6 – 10 years □ More than 10 years

2.0 How long have you been involved in railway tunnel construction projects?

□ 0 – 5 years □ 6 – 10 years □ More than 10 years

Part 3. Risk sources & measures

3.1 From your experience and observation what are the sources of risks (against completion on time) in the Tunnel construction of Awash – Weldiya railway project? In the following table risk sources/factors which are identified from literature are listed. Please identify and rate them in order of frequency of occurrence and severity/level of impact on time. You can add and rate other factors (if any). You can use '√' symbol to fill the cell with your choice of level of impact.

Level of impact:

1-very low 2-low 3-moderate 4-high 5-very high

Frequency of Occurrence: 1- Low, 2- Medium, 3 – High

S.N0	Sources of risk/causes of delay	Frequency of occurrence			Level of impact on Time				
		1	2	3	1	2	3	4	5
1	Short contract duration								
2	Legal disputes								
3	Type of contract								
4	Type of bidding								
5	Delays in payment from client								
6	Change orders								
7	Late in approving documents								
8	Poor coordination/ Poor Project Management								
9	Difficulty in financing project/ Funding Problems								
10	Rework due to errors								
11	disputes on site								
12	Ineffective planning								
13	Mistakes in design documents								
14	Lack of constructability								
15	Inadequate experience								
16	Labor shortage								
17	Unqualified workforce/ Shortage of technical personnel (skilled labour)								
18	Low productivity level of labors								
19	Labour agitation and strikes								
20	High cost of labour								
21	Labour Absenteeism								
22	Material shortage								

23	Delay in delivery of materials								
24	Damage of materials								
25	Late procurement of materials								
26	unreliable sources of local & Imported materials								
27	Inflation/Relative Price Changes								
28	Equipment breakdown and maintenance problem								
29	Shortage of equipment								
30	Low productivity of equipment								
31	Delay in obtaining permits								
32	Weather issues/ Bad weather								
33	Major and minor accidents during execution								
34	Traffic restriction								
35	Unavailability of utilities								
36	Force Majeure risks like flood, fire earthquake etc.								
37	Additional work								
38	Unexpected Ground Conditions								
39	Exchange Rate								
40	Client Knowledge								
41	Land Acquisition Costs and right of way								
42	Poor quality control								
43	Lack of Communication								
44	inaccurate quantity take – off								
45	Rock and soil suitability								
46	project location								
47	social and cultural impacts								

if any other, please specify									

3.2 From your experience and observation what are the measures taken to minimize or avoid the sources of risks and their impact on time in the Tunnel construction of Awash – Weldiya railway project? List and rate them based on their significance in time management.

Relative importance: 1 –Not important, 2 –low important, 3–Moderately Important, 4 -Important, 5 - Very important

S.N0	Description of measures taken/mitigation action	Relative importance/significance in time management				
		1	2	3	4	5

3.3 Based on your personal view what is the performance of tunneling work in Awash – Weldia railway project? Circle the one which you agree:

1-poor 2- fair 3-good 4- very good 5- excellent

3.4 What are the problems faced during construction of the tunnels?

_____
_____
_____
_____
_____

3.5 What is your general opinion about the Tunnel construction project regarding construction practice and time overrun in Awash Weldiya railway project?

_____
_____
_____
_____
_____

3.6 Any comment regarding to the idea of the thesis work:

_____
_____
_____

Appendix B: Some Geological Pictures



View of the south portal area of tunnel T-02 (left) and View of the north portal area of tunnel T-02 (trachybasalt overlying rhyolite at the portal location) on the right (Geotechnical report tunnel T-02 report number 1004 version 1, 2016)



Rhyolite outcropping at the proposed north portal location (Geotechnical report tunnel T-02 report number 1004 version 1, 2016)



South portal excavation (left) and North portal excavation (right) (Geotechnical report tunnel T-03, report number 1005 version 0; 2015)



Tunnel face at south portal (left) and General view from north of the north portal area of tunnel T-04 (right). Note the drainage channel in the foreground (Geotechnical report tunnel T-04, Portal areas, report number 1001 version 1; 2015).



View of the south portal area of tunnel T-05 (left) and View of the north portal area of tunnel T-05 (right) (Geotechnical report tunnel T-05,report number 1006 version 0; 2016)



Excavation works (entrance & exit of T6) (Weekly progress report, March 2016)



View of the south portal area of tunnel T-07 and View of the rock exposed near north portal area on a borehole access road cut respectively (Geotechnical report tunnel T-07 report no. 1003 version 1, 2015)