Analysis on Road Safety Inspection using Analytical Hierarchy Process (AHP) Method

A case study in Addis Ababa city

Menbere Getahun

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This is to certify that the thesis prepared by Menbere Getahun, entitled: **Analysis on Road Safety Inspection using Analytical Hierarchy Process (AHP) Method (A case study in Addis Ababa city)** and submitted in partial fulfillment of the requirements for the degree of Master of Science (Road and Transport Engineering) compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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Dr. Getu Segne *External Examiner*	______________ *Signature*	______________ *Date*
Dr. Bikila Teklu *Advisor*	______________ *Signature*	______________ *Date*

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DECLARATION

This thesis entitled "Analysis on Road Safety Inspection using Analytical Hierarchy Process (AHP) Method" is my original work performed under the supervision of my advisor Dr. Bikila Tekilu has not been presented for a degree in any other University. All sources of material used for this thesis have been duly acknowledged.

Signature________________________

Menbere Getahun

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ABSTRACT

Road infrastructure safety is a world issue. Many researches have been done to solve road safety problems. There exist two types of internationally recognized engineering approaches to counter road safety problem, the Proactive and the Reactive approach. In the Reactive Approach, safety improvement interventions are taken after many accidents have already occurred. Whereas Proactive Approach encompasses accident prevention and adoption of corrective measures before accidents can take place. The main objective of this research is contributing to the overall effort in preventing accident occurrence proactively. The study uses both qualitative and quantitative methods of analysis. A simple random sampling was used to select the road section for road safety inspection. The analyses of the research mainly use analytical hierarchy process (AHP) method of pair wise comparisons to distinguish the road components that has a significant effect in contributing to the likelihood of road traffic accident by taking the focus group judgments. In addition two levels of AHP were used to select the road sections with good road way facilities. This study considers four major factors which are road geometry; road surface; traffic sign, road marking and lighting and road side environment. It's found that the pavement surface condition and cross section of the roads are the significant factors in contributing to the accident occurrence. Finally, in conclusion, AHP is suitable for analyzing the qualitative findings of the field result and identification of the significant factors by keeping the consistency of the judgment.

Key Words: - **Road safety audit, Road safety inspection, Analytical hierarch process, Pairwise comparison.**

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ABBREVIATIONS AND ACRONYMS

WHO -World Health Organization

RSA - Road Safety Audit

RSI - Road Safety Inspection

AACRA- Addis Ababa City Roads Authority

ERA- Ethiopian Roads Authority

FHWA - Federal Highway Agency

UK – United Kingdom

RSAR – Road Safety Audit Review

CRF – Crash Reduction Factor

ROW- Right of Way

BP – Beginning Point

EP – Ending Point

AHP – Analytical Hierarchy Process

MCDM – Multi-criteria Decision Making

CR – Consistency Ratio

CI – Consistency Index

RI – Random consistency Index

PAS – Principal Arterial Street

SAS – Sub Arterial Street

CHAPTER 1

INTRODUCTION

1.1 Background

Road traffic accident is a world issue. In low-income countries with 1% registered vehicle there is 16% of road traffic deaths the remaining 74% occurred in middle-income countries. These indicate 90% of road traffic deaths occur in low and middle-income countries. (WHO, 2015). Based on modeled numbers, the 10 countries with the highest number of deaths are: China, India, Nigeria, the United States, Pakistan, Indonesia, the Russian Federation, Brazil, Egypt and Ethiopia (WHO, 2009).

Addis Ababa takes the highest number of traffic accident out of other regions with in the country. The number of road fatalities in 2015 is 448 (*i*RAP report Ethiopia, 2016).

A safe road environment should offer no surprises to road users, adequate guidance throughout the route, controlled release of information – not too much of a given point or over a short length of road, repeat information where necessary to reinforce the message, and forgive road users if these principles fail (SARSAM, 2012).The Highway Safety Manual indicates that thirty-four percent (34%) of all the crashes are caused partly or fully due to Roadway Factors. There exist two types of internationally recognized engineering approaches to counter road safety problems the Proactive and the Reactive approach. In the Reactive Approach, safety improvement interventions are taken after many accidents have already occurred. In many countries, adoption of reactive approach could not gain significant success due to the absence of standard requirements needed for such approach. The Proactive Approach encompasses accident prevention and adoption of corrective measures before accidents can take place. One of the proactive interventions is Road Safety Audit (RSA)/Road Safety Inspection (RSI) and that is a relatively new tool in the developing countries. RSA/RSI is in essence, crash prevention tool (Ahmeda et al., 2013).

RSI is recognized as a relevant infrastructure safety management tool in several countries; however, procedures for its practical implementation differ from country to country (Cardoso et al., 2005).

Best practice road safety audits assess safety for all road users, including pedestrians, cyclists and motorcyclists. A key part of the solution for improving road infrastructure is assessing the road network identifying which are the most dangerous roads, who uses these roads and which road users are most likely to be injured can all help to decide which affordable engineering countermeasures are most essential for upgrading the road and making it safer (WHO,2015).
Therefore carefully examined the cause that will contribute to traffic accident occurrence or factors that may increase the severity of accident and identification of road deficiencies within the city using safety audit has a great importance to carry out proactive remedial measures.

1.2 Statement of the problem

A road safety audit manual is developed by ERA but there are no obligatory or encouraging conditions by road authorities to implement road safety audit on the road projects. Mostly the entire section or geometry of the road is not subjected to change within a short period, but the pavement condition, traffic signs, road markings and road side environment may change due to different reasons. Those road elements have a significant effect on road infrastructure safety. However there is no road safety inspection guide line to check the existing condition of road infrastructure with respect to safety.
This study tries to find deficiencies proactively that may cause or contribute to the occurrence of road traffic accidents due to lack of regular road safety inspection for the roads in the city during their service time instead of applying reactive accident cause identification method.

1.3 Research questions

1. How can road safety inspection be used as a tool to identify deficiencies that are contributing to the likelihood of traffic accident?
2. How AHP can be used for analysis of RSI findings?

1.4 Objectives of the study

1.4.1 General objective

The general objective of this research is to contribute for the overall effort in preventing accident occurrence by identifying accident contribution factors proactively in order to create safe road way facilities in the city of Addis Ababa.

1.4.2 Specific objectives

- To conduct road safety inspection on the selected road sections and identify deficiencies that may contribute for the occurrence of road traffic accident.
- To apply AHP for analysis of road safety inspection findings.

1.5 Significance of the Study

This research contributes to the state of the art about how the subjective and qualitative results of road safety inspection practices are analyzed quantitatively for making scientific decisions in order to solve the problems.

In addition, the research attempts to contribute to the efforts of road safety inspectors and road authorities. First, road safety inspection in general road safety audit is not thoroughly applied from inception to completion of the project road. Therefore, the result of this study will give an insight on the practice of road safety inspection and its importance on proactively identifying problems that may cause to road traffic accident. Second, the findings may influence road authorities and engineers to consider road safety inspection while the roads are providing service. Finally, it helps either for the road authorities or the concerned bodies to easily understand what type of measures shall be considered primarily in order to prevent road traffic accidents.

1.6 Scope of the Study

The scope of this study is conducting a road safety inspection or the fifth stage of road safety audit which is an audit applying on the existing road, based on AHP quantify the inspection result and identifying deficiencies only related to the engineering factors that will contribute for the likelihood of accidents. It doesn't include a detail accident data analysis to identify the factors or the cause that are contributing to road traffic accident.

1.7 Limitation of the Study

The research is limited to those selected roads in the city due to time and budget constraints. In addition the researcher faces challenges due to the absence of well documented accident data, absence of practices in the city on the subject area of this study and lack of equipped vehicle to conduct the inspection.

1.8 Thesis Organization

This research is divided in to five main Chapters. The first chapter intends to introduce the general background of the study, the statement of research problem, research questions, significance of the study and the objectives.

In the second chapter the literature review is presented by reviewing all the necessary literatures in the area of the study. Methods and materials used to conduct this research are presented in the third chapter. The study area, study design, data collection, equipment and software used for the study are explained in this section.

In the fourth chapter the results and discussions are presented. Finally chapter five describes the conclusions and recommendations of the study.

CHAPTER 2
LITERATURE REVIEW

The main purpose of this review is to provide clear understanding about the concept of road safety audit, practice of RSA/RSI and factors that affect road safety. In addition different methods used to rate the RSI results are included.

2.1 Definitions and Concept of Road Safety Audit

Road Safety Audits (RSAs) have been practiced in many countries following the guidelines of their own. The concept and practice of road safety audit is varies with in different countries. This section explains the definitions and practice of road safety audit in various guidelines and studies.

In Austria, RSA is to be conducted during the planning of new road sections and the redesign of existing roads. This is a *safety review that is designed to identify safety deficiencies and propose measures to rectify these deficiencies.* (RSI, 2014).

RSA is described as a systematic and independent examination of a project designed to highlight potential security issues at the earliest possible stage of planning and construction, to reduce or eliminate these problems and limit the risk for different types of road users.(Pilot4safety,2012).

A Road safety audit is to ensure that new road and traffic systems are designed to prevent fatal or permanent injury accidents from occurring (Vision Zero). (Manual V720E, 2014).

In South Africa, Road Safety Audit is a formal examination process of a new or upgrading project where interaction with road users takes place, in which an independent and qualified team identifies potential road safety problems and suggests measures to mitigate those problems. (SARSAM, 2012).

RSA as a formal systematic road safety assessment or “checking” of a road or a road scheme. It is a systematic procedure that brings traffic safety knowledge into the road planning and design process to prevent traffic crashes. (ERA, 2004 &ADBM, 2003).

The FHWA manual clearly define what road safety audits are and what RSA are not to avoid the misinterpretation of RSA with quality control of the design. RSAs represent an additional tool within the suite of tools that currently make up a multidisciplinary safety management system aimed at improving safety. (FHWA, 2006).

As such, RSAs are not a replacement for:

- Design quality control or standard compliance checks also known as "safety reviews of design"
- Traffic impact or safety impact studies
- Safety conscious planning
- Road safety inventory programs
- Traffic safety modeling efforts

Confusing RSAs with the quality control of design is the most common misinterpretation of the role and nature of an RSA. Compliance with design standards, while important, does not necessarily result in an optimally safe road design and, conversely, failure to achieve compliance with standards does not necessarily result in a design that is unacceptable from a safety perspective. (FHWA, 2006).

According to the above definitions of road safety audit, Different countries have their own explanation. However their theme is more close to each other.

A comparative study defines RSA by considering three important and critical terms. Those are related to stating that an RSA is (Ahmeda et al., 2013):-

a) A formal examination or procedure that makes it different from general safety surveys.

b) Conducted by independent and qualified professionals

c) Conducted before, during and after a project is completed.

A RSA systematically identifies safety issues, and provides recommendations for how the design can be improved to remediate against those issues. Beside RSA have five stages as described below.

Stage 1: Feasibility Study

Audits at this stage can influence fundamental issues such as design standards (including design speed and possible speed limits), cross-sections, route choice, impact on the surrounding road network, and the number, location and type of intersections (RSMA, 2014).

Stage 2: Preliminary Design

The preliminary or draft design will determine the standards, the cross-section, the alignment, and the layout of intersections. The Preliminary Design RSA will check all of these elements, but will also look at wider issues, such as (ADBM, 2003):

- The specific needs of all likely road users
- Access to adjacent property
- Safe accommodation of local traffic movements
- Adequate and safe connections to the existing road network

Stage 3: Detailed Design

It is a chance to check all of the proposed details, such as signs and markings, safety barrier provision, road-side obstacles, visibility conditions at intersections, non-motorized user facilities and connections to existing roads (ERA, 2004).

Stage 4: Pre-Opening

A Pre-Opening RSA takes place immediately before the road or scheme is opened to traffic, and involves a detailed inspection of the road, all of the signs, and other road furniture. It must include examination of the completed scheme both in daylight and in darkness to assess any specific issues that may occur at night (often this will concern how the road is perceived by drivers when it is dark) (RSMA, 2014).

Stage 5: Post-Opening

A Post-Opening RSA is completed after the road has been open for about a year and prior to the end of the maintenance period. This will show how the road is actually being used, and, if there are any problems, they will most likely be apparent already. It may be possible to make minor changes before the contractor fully demobilizes. (RSMA, 2014).

A study on the seven countries of RSA guidelines were done by considering the parameters which are; definition of RSA in the guidelines, stages of a project when RSA is recommended, road Safety checklists/forms attached to the document and other important parameters of a guideline document like qualification requirements and composition of the audit team, consideration of legal liability aspects in RSA, Inclusion of work flow charts of audit in the document and sample reports and/or case studies on overall process and/or various stages of RSA (Ahmeda et al., 2013).

Three countries were represented comparatively low-income economic conditions. Those countries are i) Bangladesh ii) India and iii) Nepal. One of the countries were represented the middle-income scenario i.e. Malaysia. The Remaining three countries were represented the developed world i) Ireland ii) The United Kingdom (UK) and iii) The United States of America (USA) (Ahmeda et al., 2013).

Based on the findings of the comparative review among the selected seven countries RSA guideline documents, the following recommendations were made (Ahmeda et al., 2013):

a) Consistency in the definitions is the prerequisite for setting the procedure of a detailed program of works among countries.

b) The RSAs are needed to be carried out at different stages of the project starting from the feasibility study stage to post construction stage and also for the existing roads. The study recommends that RSA guideline should address and provide guidance on the audit procedure for the existing roads as well.

c) An individual agency should include forms/check lists for various stages of audit and special features of design and special forms for audit in unusual circumstances in their guideline documents.

d) The minimum qualifications and specialization of the auditors and the composition of the audit team are important elements of an RSA guideline.

e) RSA guideline documents should address the legal liability issues and should provide reference to appropriate documents for detailed information.

f) An overall or stage-wise flowchart (depending on the overall structure of the document) of the audit activities to be included in the guideline document to provide a clear picture of the steps to be followed in the audit process.

g) Include case study reports or/ sample RSA reports in the appendix section of the guideline document to facilitate clarification about the main texts of the guideline document.

According to the above reviewed study and recommendation the ERA RSA manual also miss some points this are:

- It doesn’t describe the minimum qualifications and specialization of the auditors and the composition of the audit team.
- Does not contain any information on the legal aspect of the RSA.
- Don’t provide an overall or stage-wise flowchart (depending on the overall structure of the document) of the audit activities
- Do not include any sample RSA report or sample case studies.

2.1.1 Benefits of Road Safety Audit

Since the concept and application of RSA is new, there is no study conducted in Ethiopia on the benefits of RSA. However studies in developed countries show that it has a large benefit in solving road safety problems than its cost to implement it.

It is evident that the benefit of undertaking RSA outweighs the cost incurred to conduct it. In the UK, for instance, the Lothian Regional Council has estimated the benefit-cost ratio of the RSA as being 15:1, while transit New Zealand has estimated the benefit cost ratio as 20:1. Consequently, there seems to be evidence from developed countries that significant benefit can result from introducing the RSA procedures (ERA, 2004).

One study revealed a first year rate of return of 146%, a wonderful return in any language. And the cost of an audit is low (in the order of 0.2-0.5% of the total project cost: the higher the total project cost, be lower this percentage drops). With such low costs and high returns road safety audit is a process that should appeal to all levels of governments in all countries (Pikunas and Pumputis, 2010).

2.2 Road safety inspection (RSI)

Road safety inspection is referenced as a Road Safety Audit Review (RSAR) in US literature, Road Safety Appraisal in South African literature or Road Safety Inspection in European literature.

Road safety inspection (RSI) is a strategic comparative analysis of the impact of a new road or a substantial modification to the existing network on the safety performance of the road network (BALTRIS, 2012).

An RSI is the assessment of the state of a road section (for a road network) in terms of road safety, the physiology of perception, and psychology according to the principles of quality assurance to eliminate existing proven accident risks and hazards (RSI, 2014).

A Road Safety Inspection (RSI) is a systematic, on site review, conducted by expert(s), of an existing road or section of road to identify hazardous conditions, faults and deficiencies that may lead to serious accidents. It is important to note that (PIARC, 2007 and SEETO, 2009):

- A RSI is systematic – this means it is both comprehensive and carried out in a methodical way.
- A RSI relates to an existing road not roads being constructed.

- A RSI is pro-active, trying to prevent accidents rather than responding to recorded crashes.

RSI is a proactive safety management tool. It comprises a routine, programmed and systematic field survey which is undertaken proactively on existing roads to identify risk factors and to achieve enhanced safety. An RSI is a standardized survey undertaken to collect prescribed data relating to road characteristics (highway and environmental features) of existing roads. This allows the identification of sections of road that warrant further road safety investigation (RSMA, Existing road).

For this research a definition of RSI developed by world road association is adopted. Which is "*RSI is a systematic, on site review, of an existing road or section of road to identify hazardous conditions, faults and deficiencies that may lead to accidents*."

2.2.1 Difference between RSA and RSI

Road safety audit and road safety inspection is a systematic work method contributing to safer roads and safer road traffic. In some older references the term of audit could cover also the present road safety inspection procedures. Road safety inspection of existing roads is a today's concept that has been adopted because this term appears to be more appropriate when associated with existing roads. In spite of this, road safety audit and road safety inspection have several similarities, but also essential differences (BALTRIS, 2012).Seefigure2.1.

In Ethiopia there is no guideline or study on what road safety inspection is and when to conduct it. The concept of RSI is very similar to the fifth stage of RSA which is monitoring existing road or post opening audit. But manuals and studies show that even if they have similar characteristics RSI has its own guideline and procedures to implement. However the major difference between RSA of existing road and RSI is; RSA conducted for new road schemes whereas RSI is conducted for roads in operation based on scheduled time in order to check the safety effect of the road and its environment.

In Austria a road safety assessment after the opening of the road for traffic is called road safety inspection; whereas the assessments during the planning (or redesign) stage are road safety audits (RSI, 2014).

ERA road safety audit manual describe about road safety audit of existing roads which is conducted after a few months when the roads are opened to traffic. It can also be used to assess whether an existing road or a road network is operating safely. This definition contains the concept of post opening road safety audit stage and RSI together. But other countries manual states that this type of audit is an audit to show how the road is actually being used, and, if there are any problems, they will most likely be apparent already. It may be possible to make minor changes before the contractor fully demobilizes. As a result most of European countries develop an independent road safety inspection guideline or manual to conduct an inspection based on scheduled time and procedure for roads in operation.

Reducing highway crashes is a priority of the Administrations in Europe and elsewhere. One means of reducing them is to detect and correct roadway deficiencies. Road Safety Inspections (RSI), established for this purpose, has proven to be an effective tool for the management of safety on existing roads (Lopez et al., 2016).

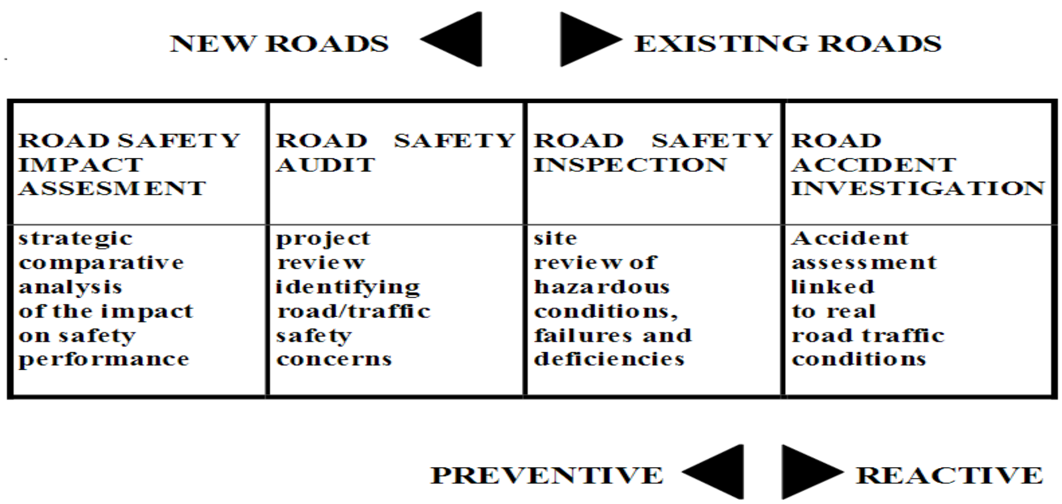

Figure 2.1 Road safety improvement systems (PIARC, 2007)

2.2.2 Reasons and selection criteria for Conducting RSI

Inspections can lead to reductions in the likelihood of accidents, severity if an accident does happen and the need for costly remedial work (PIARC, 2007). An RSI can be initiated (RSI, 2014):

- When a concentration of accidents is observed, especially with diverse type structures.
- When evidence, problems, or other information make an inspection prudent.
- When there are safety deficiencies, hazard potential, or the same types of accidents on longer sections.

Any road can be inspected, but a road authority may wish to prioritize for some reason, including funding restrictions. The prioritization could be based on location, traffic volume or accident data. As mentioned above, accident data can assist by indicating the worst roads in terms of crashes and these roads could be the first roads inspected (PIARC, 2007).

Accident or hazard information from police, road maintenance agencies, or other offices and persons can also be reason to conduct an RSI (SEETO, 2009).

There are various methods to rank or prioritize road sections for conducting road safety inspection. Which are:-

- **Ranking of a Road Category by Volume of Traffic** (RSI,2014)

If a single road category is being considered (for example only provincial highways); ranking can be completed easily by conducting RSI on the roads with the highest traffic volume first.

Advantage: As many road users as possible benefit from improvements

Disadvantage: When the ranking is conducted solely on the basis of this criterion without taking accidents into account, sections with a high concentration of accidents could be ignored.

- **Ranking by Accident Density** (RSI,2014)

Another simple ranking method is via the accident density. Here, the number of accidents on a section is divided by the length of the section.

Advantage: Sections with a high accident concentration are covered

Disadvantage: The accident density depends heavily on the selected section length – short sections may be overrepresented

- **Ranking by Accident Rate** (PIARC, 2007)

If traffic statistics are available for a network, these can be used for ranking by calculating the accident rate.

Advantage: Sections with a high accident concentration are covered

Disadvantage: As for the accident concentration, the result is highly dependent on the volume of traffic. Too much attention could be paid to sections with a low level of traffic and a small number of accidents in absolute terms.

- **Ranking by Reduction Potential** (RSI,2014)

The reduction potential can be based on different accident parameters; this is usually determined using accident rates or accident cost rates, with the latter also implicitly including the severity of accidents in the assessment.

The reduction potential is usually determined in multiple steps:

- First, the existing road network must be divided into homogeneous sections (uniform traffic volume, road design parameters, no switch from interurban to urban, constant cross section, etc.).

- Calculation of accident parameters in the individual sections

- Determination of the sections with the highest reduction potential

Advantage: Effective system, high success potential

Disadvantage: Complex and involved calculation

Most frequently, main criteria for the selection of inspection sites include the accident rate (Netherlands, Belgium, Portugal, Hungary and Switzerland) or requests from public or police (Hungary and Switzerland). Independent, automatic, periodical inspections are implemented, or at least recommended, in Germany, Hungary and Austria (Cardoso et al., 2005).

For this study accident density method were used to prioritize the road sections that should be inspected.

2.2.3 RSI and Accident Data

A RSI does not require accident data. Therefore, the RSI have big advantages in cases with no reliable accident data. It is a systematic review of a selected road or relatively long section of a road, regardless of the number of accidents. The traditional road engineering approach to safety has very often been some kind to "wait and see" approach, i.e. safety countermeasures are not considered until the accident situation becomes unacceptable (BALTRIS, 2012 and SEETO 2009).

There are two approaches of road safety measures which are proactive and reactive approach. Since RSI is a proactive concept, Proactive approaches can be useful where crash data are not yet available or where details such as precise crash coordinates are not recorded. While proactive approaches are useful, they do not replace the need for good quality crash data to guide and direct road safety practices (RSMA, Existing road).

When considering the accident situation on a road section, it is important to think proactively, i.e. not focusing on what has happened, but more on anticipating what can happen in the future.

One never knows where the next accident will occur. One should not be too focused on previous accidents on the road section, but rather gain a rough overview of the accident situation along the section. The reason for this is that it is easy to focus too much on past occurrences and overlook other hazardous conditions. It is the general accident picture of the section that should be focused on and not the locations where the individual accidents have occurred. This is achieved through a simple accident study in order to check if there are other factors that typify the accident picture (time of year, time of day etc.) (Manual V720E, 2014).

In addition, traditional safety reviews and investigations of crash history rely primarily on crash data to determine what safety issues are occurring at the site. They are reactive as they mainly identify safety issues after a crash or pattern of crashes have occurred and are often initiated in response to an unusually high number of crashes occurring along a section of road or at a particular intersection or interchange. In contrast, RSAs of existing roads rely mainly on the site visit, as-built design drawings (if kept up to date), and other project data (e.g., previous reports) to determine what safety issues are expected to arise at the site. This will provide the RSA team with an accurate picture as to the level of safety on the road. For this reason, RSAs are proactive as they can identify where crashes will likely occur and what will be their resultant severity. Crash data, if available, should be used to supplement any findings made as a result of the site visit and review of project data. However, the RSA team may choose not to examine the crash history until after the project data review and site visit have been completed so that their evaluation is not biased by the crash data. Also, crash data is often dated and doesn't always help in determining emerging operational trends or safety issues at a location. (FHWA, 2006).

If there is available accident data it can be assessed according to the following criteria for the evaluation (RSI, 2014 and FHWA, 2006):

- Crash location
- Severity (Injuries and fatalities) in the section in question
- Crash type
- Light conditions (day/night/artificial lighting)
- Road condition (dry/wet/ice)

2.2.4 Frequency of Road Safety Inspection

No exact timing is recommended, timing should be decided by every country individually. Some research recommends that five years regular period for RSI is adequate but always before the reconstruction design has been started (BALTRIS, 2012 and RSMA, Existing road). RSIs are to be undertaken across a significant proportion of the road network every 3-5 years.

Countries don't have specifications for RSI frequency: once every two years in Germany, and once every five years in Portugal and Hungary. Generally the periodical execution of RSI is hindered by the lack of legal obligation to inspect roads (Cardoso et al., 2005).

Design features such as cross-sections and alignment will not change during the years but may have to be adapted to changing functions, traffic amount and composition. A regular inspections regime could see a road inspected fully once every four to ten years depending on the development of traffic and road functions. Other road elements will meet changes more often. If road conditions are known to have changed e.g. new signing and/or markings, new plantings, lighting and surface conditions, a focused or specific road safety inspection limited to these topics can be carried out by the road administration. These inspections are essentially checking works undertaken to make sure no errors that can lead to accidents have been made (PIARC, 2007).

2.3 International practice of RSA and RSI

This section tries to give an insight on the international acceptance of RSA/RSI and its practice throughout different countries.

RSAs have been used for more than 20 years, beginning with the United Kingdom. The United Kingdom has advanced the applications of RSAs to the point where it is mandatory for all trunk road highway improvement projects and also mandatory to conduct an RSA monitoring process of all projects that have involved an RSA (NCHRP, 2004).

Australia and New Zealand began using RSA's in 1990 following exchanges and visits by road safety engineers from the United Kingdom. RSA's were first introduced on existing roads as well as on design projects (Jones, 2013).

A number of other countries are involved in conducting RSAs. Other RSA participants include India, Thailand, and others in Southeast Asia; South Africa; Eritrea in Northeast Africa; and

Denmark, Finland, Germany, Italy, Norway, The Netherlands, and Switzerland in Europe (NCHRP,2004).

Similarly RSI are carried out in different European countries even if it is not executed in all countries. Study show that RSI or similar procedures are performed in eight European countries (Austria, Belgium, Germany, Hungary, Netherlands, Norway, Portugal and Switzerland. Two countries (Germany and Hungary) do have a legal basis for RSI; in four countries (Germany, Hungary, Norway and Portugal) RSI are compulsory. In general RSI is carried out by National Road Administrations as part of, or in addition to, general maintenance inspections. In Austria, Belgium, Norway, Portugal and Switzerland a standardized approach exists for RSI.

In The Netherlands the checklist is based on the guidelines for Road Safety Audit and Design Guidelines for Motorways. In Portugal the checklist is an internal document of the Portuguese Road Administration (Estrada's de Portugal, EP-SA) containing recommendations for the implementation of inspections and a list of the most frequently detected hazards on main roads of the National Road Network (Cardoso et al., 2005).

Finally it was concluded that no country had distinct RSI procedures for each road category. Germany was the only country where RSI are carried out in the entire road network. In The Netherlands, Hungary and Portugal RSI are performed exclusively on state main roads. In Switzerland, Belgium and Norway RSI are executed only if the safety level of a specific section or junction needs to be assessed.

2.3.1 Practice of RSA and RSI in Ethiopia

In Ethiopia there is a road safety audit manual developed by Ethiopian roads authority (ERA).Quality assurance, road inspection & safety management bureau of ERA inspect the roads in order to assure its quality. According to the definition stated on the ERA manual, RSA is usually carried out by an independent qualified auditor or a team of auditors who report on ways of minimizing risks to road users. In addition different literatures on RSA indicate that, RSA shall be conducted independently by keeping its own methods and procedure because RSA is not a tool to check the quality of the road or to judge one road is better than another rather it is a method to solve or to mitigate road safety problems proactively.

The concept of RSI inspection is included in the ERA road safety audit manual which is the fifth stage of RSA activity. However there is no independent procedure or guideline in the country for the implementation of road safety inspection that will provide a clear guidance about how, when and by whom will roads shall be inspected.

Generally it can be concluded that practice of RSA/RSI is not introduced all over the country. It requires more attention of road authorities to implement RSA/RSI in the road projects.

2.4 Factors Affecting Road Safety

There are various factors affecting the safety of road users. On these research four major components of road is considered in order to study the effect of road on safety. A report indicate that, in Ethiopia, the police have limited road and traffic engineering skill in general and thus they underestimate the contribution of roads and environments to traffic accidents and specially they lack trainings on subject area (Segni, 2007).

2.4.1 Geometric components of the road

The geometry of the road basically consists of horizontal and vertical alignment. The alignment of the roadway has a great impact on road safety because a driver's ability to see ahead is necessary for the safe operation of the vehicle and thus for the overall safety of the System (Ahmed, 2013).

Studies show that accidents mostly occur at curves. Accident rate and curve radius have a close relationship. This means, accident rate reduces as the radius of the road increases; and the curves with the same or similar radius are safer than with different radius (Gebremeskel, 2014). Another study shows that increasing radii cause lower accident frequency. Radii smaller than 500m associated with higher accident rates. In contrast to the horizontal alignment, the vertical alignment has a smaller impact on road safety (Pilot4safety, 2012).

The vertical grades or curvature of vertical curves of the roadways are also related to road safety. When steeper slopes are provided, it becomes more difficult for a vehicle to be controlled. Generally, Steep downgrades are critical because of the fast increasing speed, while step upgrades are critical because they might lead to great differences in speed between Lorries and Cars. A two-lane highway located in steep terrain can have 15% more road crashes than a similar road located in a level terrain condition. Therefore, presence of a climbing lane (additional lane) for heavier vehicles can reduce probability of crashes by 25% on a two lane roadway section (Ahmed, 2013).

2.4.2 Cross-Sectional elements of the road

Most studies agree that lower accident rate is attributed to wider lanes. But it seems that there is an optimal lane width of around 3.50m(Ahmed, 2013) .On four types of lane width which are 9 ft, 10 ft, 11 ft and 12 ft. it was found that Roadways with 10 ft travel lanes experience the highest crash frequency relative to other lane widths. Roads with 9 ft travel lanes were found to experience the lowest relative crash frequency. It was concluded that this may be due to increased driver caution when traveling on narrow lanes (Wood, S. et al., 2015). It is reasonable to assume that wider lanes may provide additional space to the driver to correct potential mistakes and thus avoid crashes. Lane and shoulder conditions directly affect run-off road (ROR) and opposite direction (OD) accidents (Mohammed, 2013).

The effect of shoulder width and shoulder paving material goes hand-in hand with lane width, and road side events. Increasing the shoulder width is associated with a decline of accidents. 21% reduction of total accidents was determined on road with shoulders of 0.9m-2.7m compared to road without shoulders (Mohammed, 2013). Shoulder paving was associated with a statistically-significant reduction in casualty accident frequencies. The main accident reductions were in rear end, overtaking out of control, off carriageway to left, and off carriageway to right into fixed object accidents (Ogden, 1997).Shoulder wider than 2.5m give little additional safety. The other road component, median is widely used for separating the opposing traffic flow. In addition it has significant effect in reducing head on collision. Medians, particularly with barriers, reduce the severity of accidents (Mohammed, 2013).

2.4.3 Pavement condition

Driving on a smooth pavement section is much easier than a rough pavement and fewer adjusting actions are needed to control the vehicle. Driving on a rough road, with continuous exposure to vibrations and shake, causes driver fatigue and increases the chance of collisions (Tehrani et al., 2016).On different studies the effect of pavement condition has given different conclusion related to safety. Ruts, cracks and unevenness in the road surface reduce driving comfort and can be a traffic hazard (Pilot4safety, 2012). One of the most significant aspects of the road component is roughness, which affects the driver and vehicle. Zero inflated Poisson (ZIP) and negative binomial (NB) regression were used to estimate the relationship between the number of collisions and the road international roughness index (IRI) value and rut depth. Based on the outcomes, IRI and number of collisions are correlated; the number of collisions increases with increasing IRI. Results did not find any statistically significant relationship between rut depth and collisions. According to published literature, rut depths greater than 7.6 mm can present a safety concern when water accumulates on the pavement surface (Tehrani et al., 2016).

Wet pavement friction is most associated with crash frequency in the presence of road factors that tend to increase the need for unexpected braking, such as curves and driveways. The study recommend locations where improving the wet pavement friction will most reduce crashes include sections with curves on undivided roads and sections with driveways or curves on divided roads (N.Ivan et al., 2012).

In contrast to the above studies, other study show that there is no strong correlation between pavement condition and traffic safety, however some design and planning issues like the degree of curvature of horizontal and vertical curves and number of towns/villages on the routes seem to play an important role in traffic safety (Mohammed et al., 2015).

2.4.4 Traffic sign, road marking and lighting

Traffic signs, road markings and lighting have a significant importance in delineating and guiding the traffic flow. Signaling roads is one of the foremost tasks of RSI.A road that is improperly or poorly signaled can lead to incorrect placement or maneuvers of vehicles and ambiguous situations increase the risk of crashes. An analyses between the relationship of road crashes in two-lane rural highways and certain deficiencies in signaling give the results that deficiencies such as “incomplete removal of road works markings” or “no guide sign or in incorrect position” are the ones associated with a higher probability of crashes in two-lane rural highways (Lopez et al.,2016).The main effect of the signs is reducing the number of accidents in lesser measure they reduce accident severity by inducing lower speeds in dangerous sites (Montella, 2003).

The study on optimizing the position of a warning sign on a sharp curve conclude, a warning sign placed at different positions prior to a sharp curve will have different influence ranges for drivers approaching and negotiating the curve. Meanwhile, different positions of a warning sign imposed different effect obviously on the adjustment of vehicle's lane position on sharp curves with the same radius, especially at the midpoint of a sharp curve. The evaluation results of five positions (0 m, 50 m, 100 m, 200 m, and 400min advance) showed that only when the warning signs were placed 100m or 200m prior to sharp curves, can they achieve positive influence on driving behavior (Zhao et al., 2014) .This finding indicates that unless signs are placed at proper distance or location from the road it may not provide its intended use.

The objective of road lighting is to reduce the accident rate in the dark: lighting makes it easier to see the road, other drivers and the immediate surroundings of the road (Pilot4safety, 2012).Lighting design is based upon whether the principal purpose of the lighting is for traffic or for pedestrians. The benefits of a high level of street lighting, especially at intersections, are well documented with a strong correlation to night-time accident reduction. Street lighting should provide a driver with a clear view of the road alignment.

2.4.5 Roadside environment

With no proper regulations, guidelines or examples of good practice, roadside environments are posing a serious danger to safety (Budzynski et al., 2016).

Accident frequency can be reduced removing or relocating roadside hazards so as to provide a clear zone along the roadside that provides errant vehicles an opportunity to recover and return to travel way or to come to a controlled and safe stop. Accident severity can be reduced making the hazards forgiving and shielding the hazards with road restraint systems (Montella, 2003).

Road restraint system like guard rail has a great impact against run off road crush. Study show that Vehicles often end up behind the guardrail because the length of the guardrails installed before hazards is too short; this can lead to a collision with a shielded hazard. It was also concluded that if hazards are present at the roadside, they need to be shielded with guardrails. To protect vehicles from impacting roadside hazards when moving behind the guardrail, the length of the barrier must be of adequate size. (Tomasch et al., 2011).

2.5 Methods to Quantify/Rate Road Safety Inspection Data and Result

Even if RSAR/RSI has a qualitative nature different studies tried to quantify/rate the audit results using different methods.

A study to quantify the risk on an urban roadway was conducted using RSAR data. On this study seven categories were included which are signs, traffic control devices(TCD), pavement, road side hazard, sight distance, cross section and pedestrian/bicycles. For each category five questions were asked to assign a risk rating. For each questions the numerical value from 0.00 to 0.85 were assigned as lowest risk level to highest risk level respectively. Then the category weight determined using CRF of Kentucky transportation center and desktop reference manual for crash reduction factors. All of the questions in each category were summed together and multiplied by the category weight. Finally the category risk rating calculates the potential risk for each category. (Jones, 2013).

Category Risk Rating= ∑Question score*Category Weight

There was also a Rural Road Safety Index (RRSI) developed by South Dakota States University to quantify the risk observed during a RSAR on a rural roadway. These method looks at five different categories; road side obstacles, signs and delineation, cross section, alignment/accesses and road surface. For each category questions were asked that quantify the risk that each safety issue poses to the roadway. Each safety question is graded on a scale of 1 to 4, where 4 being the best grade that require no treatments. A survey was conducted to determine the weight of each category with roadside obstacles and road surface determined to have the greatest risk for roadway safety. The final score is determined by deducting the sum of all of the categories from 100. (Jones, 2013).

Rating method developed by international road assessment programme (iRAP) which is called star rating method. The star is given for the roads from one to five stars. The road with five star rating is a good road where as road with one star rating is poor roads with safety problem. Star ratings provide a simple and objective measure of the level of safety provided by a road's design and are based on highway features which have an impact on the likelihood of a crash and its severity (iRAP, 2011).The focus is on identifying and recording the road attributes which influence the most common and severe types of crash, based on scientific evidence-based research. In this way, the level of road user risk on a particular network can be defined without the need for detailed crash data, which is often the case in low and middle income countries where data quality is poor. Research shows that a person's risk of death and serious injury is highest on a one-star road and lowest on a five-star road (iRAP, 2014).

On this research the collected road safety inspection data's were analyzed using analytical hierarchy method. Analytical hierarchy process (AHP) is one of the famous methods of multi criteria decision making approach (MCDM).It was introduced by Saaty. The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain (Tiantaphyllou and H.Mann, 1995).Since road safety inspection has a qualitative and subjective nature it can involve both subjective human judgments and objective evaluation merely by Eigen vector and examine the consistency of the evaluation by Eigen Value.

2.6 Summary

This chapter presented how RSA's and RSI's are used and the benefits that can be gained through them. Additionally it showed how RSI's are proactive in nature, the relation between RSI and accident data, practice of RSI in different countries and factors that may affect road safety are described. The major conclusions that are drawn from the literature review are:-

- RSA's/RSI are proactive in nature and are focused on identifying safety risks before they result in crashes.
- RSA is implemented for new roads, whereas RSI is done for safety check of existing roads during their service time.
- The RSI doesn't require accident data but if there is, it could be used as a supplement.
- RSI is implemented in different countries with regular time interval.
- Road safety is affected by different component of the road itself.
- RSA/RSI is qualitative and subjective in nature. However, the methods mentioned in the literature review are developed to quantify or rate the result obtained from the audit or field inspection.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

In this chapter the research methods and materials are presented. Description of the study area, study design, data sources, data collection, data analysis, software and equipment are presented in section 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7 respectively.

3.2 Study area

The major study area of this research is one of the ten sub cities located in the city of Addis Ababa which is kirkos. These sub city is located in the city center, and borders with the districts of Arada, Yeka, Bole, Nifas Silk-Lafto and Lideta.

Six road segments within this sub city were selected for the case study, five of the roads are principal arterial and the remaining is sub arterial road. Descriptions about the roads are summarized in table 3.1.

The adjoining land use of the study area road segments are:-

- Commercial shops
- Hotels and picnic areas
- Petrol station
- Schools
- Public bus and taxi stops

The roads are providing service for different road user types. The identified road users on the selected road segments are:-

- Private vehicles
- Pedestrians
- Motorcyclists
- Commercial transport operators
- School bus operators

Table 3.1 Description of the study area (AACRA, 2016)

Road No.	Road Name	Road Hierarchy	ROW	Carriage way width	No of Lane both side	Carriage Way Type	Length(m)	Walkways						Coordinates(UTM: Easting & Northing)	
											Type			Zone 37	
								Right	Left	Width(m)	Asphalt	Conrete	Color Tile	BP	EP
111	Welosefer-Wengelawit	PAS-4	30	21	6	New Asphalt	2345	✓	✓	3.4			✓	475092 E 993927 N	473910 E 992617 N
114	Filamingo-Welosefer	PAS-3	40	23	6	New Asphalt	2663	✓	✓	4.5			✓	473887 E 995783 N	475092 E 993927 N
105	St. joseph-Agona Cinema	PAS-3	40	23	6	New Asphalt	2643	✓	✓	3			✓	473438 E 995873 N	473494 E 993305N
183	Mexico-Kera	PAS-4	30	21	4	Existing Asphalt	2871	✓	✓	2.7	✓			472023E 995776 N	472039 E 995555 N
32.1	Leghar – Stadium	PAS 3	40	23	6	New Asphalt	1637	✓	✓	4			✓	472483 E 995945 N	473416E 995932N
32.1	Stadium-Meskel Square	PAS 3	40	23	12	New Asphalt	359	✓	✓	20			✓	473416E 995932N	473799 E 9958 88 N
99	Dev’t Bank-Kazanchis Total	SAS1	25	13.5	4	Existing Asphalt	1010	✓	✓	2.7	✓			474035 E 996538 N	474818 E 996447 N

3.3 Study design

The study design or frame used in this study was a case study type through observational investigation. This study type is selected because; case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. Since the main objective of the study is to identify factors related to the road and its surrounding environment that may contribute to accident occurrence, this study type helps to explore and analyze each element in detail on the road segments.

During the study, the following basic road elements were considered.

- Road geometry and drainage
- Pavement condition
- Traffic sign, road marking and lighting
- Road side environment

3.4 Data Sources

Multiple data sources were used to achieve the objectives. Therefore, the data usages on this study were categorized as primary and secondary sources of data. The primary data were obtained through field inspection and the secondary data were taken from Addis Ababa city police commission; Kirkos sub city traffic police office and AACRA. The overall data collection process and the specific data obtained from the aforementioned sources are described in the following section.

3.5 Data Collection

In order to select the road that should be inspected and to identify the significant road elements those are contributing to road accident; crash data, road data and field survey data were used. The secondary data's were collected from archives of government offices and the primary data collected from filed investigation by walking during day time and by driving during night time. In addition, video recording and pictures are taken during observation. The specific data obtained from the aforementioned sources are listed below.

3.5.1 Secondary Data

The reason of acquiring data from Addis Ababa police commission is to distinguish the case study area of the research. The five years recorded road traffic accident data report of all sub cities from 2003-2007 E.C. were collected and the following data were filtered.

- Total number of accident of each sub-city and
- Total number of severe injuries of each sub-city.

Data from kirkos sub city traffic police office: - Three years daily recorded road traffic accident data of the sub city which is from 2006-2008 E.C. were obtained. The data comprised of different information about the accident but for identification of road segments and to look up the general conditions of the roads on this study, the following information was extracted. Those are:-

- Crash location
- Severity (Injuries and fatalities)
- Crash type
- Light conditions (day/night)
- Road condition(wet/dry)

Road data from Addis Ababa City Road Authority (AACRA):- After identifying the road that should be inspected, the road data from AACRA road inventories were collected and it includes;

- Road way classifications
- Road way cross section elements:- number of lanes, lane width, walk way width and ROW width;
- Vertical Alignment:-gradient (%) (from as-built drawings);
- Horizontal Alignment:-curve radius(m) (from as-built drawings)
- Pavement type

3.5.2 Primary Data

The primary data were obtained from field investigation. The field inspection was done for six different days. The video recordings were done on 24/02/2017 and 02/03/2017 for two days during the night time. The remaining four days was used to collect the data during day time.

Using the investigation form, Site investigation was done by walking at daytime and by driving during night time. The data collected from field survey includes:-

- Visibility of road way alignments during day and night time.
- Condition of road side drainages
- Road surface conditions
- Availability and condition of road markings, traffic signs and road side lightings
- Road side environment i.e. availability and condition of pedestrian facilities, parking facilities, roadside vegetation and other road side hazards.

3.6 Data processing and analysis

After collecting the necessary data, the major data analysis was done using analytical hierarchy process (AHP) of pair wise comparison method. However, simple accident data analysis which is accident density is used in order to look up the accident condition of the road sections located within the sub city. From accident data of all sub cities frequencies of accident were used to compare each sub-city and convenience sampling method was used to identify the case study area. Convenience sampling (also known as Haphazard Sampling or Accidental Sampling) is a type of nonprobability or nonrandom sampling where members of the target population that meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or the willingness to participate are included for the purpose of the study.(Ilker Etikan et al.,2016)

Accident Densities

Accident densities (AD) describe the average annual number of Accident. The density can be calculated as the ratio of the annual number of accidents and length of the road section on which the accidents occurred. The density is thus a measure of the (length-specific) frequency at which accidents have occurred during a specific period over a specific road section.

$$AD = A / L \cdot t \qquad [A/(km.yrs)] \ldots\ldots\ldots\ldots \text{eq.1}$$

Where: - A Number of accidents in t years [A]

L Length of road section [km]

t Period under review [years]

After determining the accident density of the road segments located in the sub city, random sampling is used to select the specific road segment for inspection. Based on this sampling method, all road segments have an equal likely chance of being chosen (Dowdy, et al., and C. Douglas, 2003) probabilities to be inspected. Therefore, in drawing the sample lottery based technique was used.

The significant factors that may affect the road safety were identified for each road segments and the better road section were prioritized using two levels of analytical hierarchy process (see figure 3.1). Analytical hierarchy process (AHP) is one of the famous methods of multi criteria decision making approach (MCDM).It can involve both subjective human judgments and objective evaluation. (Tiantaphyllou and H.Mann, 1995) On this research the pair wise comparison of AHP were used according to the following step. The reason behind using this method was; it is possible to check the consistency of the judgment. The judgment is given by focus groups. The focus groups are a group of five to ten people that has knowledge about the subject area (Freitas H., et al., 1998). Usually it's better to have a focus group between six to eight people (A. Richard, 2002). For this research six people were asked in order to give the judgment using questionnaires. The AHP analysis also done based on the following steps:

- Organizing RSI data and information.
- Rate the comparisons according to Table 3.2 and the pairwise comparisons of various criteria are organized into a square matrix. The diagonal elements of the matrix are 1.
- The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix were calculated. It gives the relative effect of the various criteria being compared.

  λmax=(∑each columns of square matrix *priority vector)   and Pv= (∑Each row)/n

- Then consistencies of the matrix of order n were evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level then answers to comparisons may be re-examined. The consistency index is calculated as

$CI = (\lambda_{max} - n)/ (n - 1)$……………………………eq.2

Where: -CI   Consistency index

λ_{max} Maximum eigenvalue of the judgment matrix.

Pv   Priority vector (Principal eigenvector)

The above CI can be compared with that of a random matrix (RI), RI to calculate the consistency ratio (CR).

CR=CI/RI; Saaty suggests the value of CR should be less than 0.1; RI value is taken from table 3.2

Table 3.2 Random Consistency Index (*RI*) (Tiantaphyllou and H.Mann, 1995)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Two levels of AHP analysis was done to identify the better road section based on the four major factors among the six road segments (see figure 3.1). This helps to know which road is under good condition and which road require more attention in order to provide remedial measures for the defect. Level 0 is the goal of the analysis. Level 1 is multi criteria that consist of several factors. The last level (level 2 in figure 3.1) is the alternative choices of road sections. The lines between levels indicate relationship between factors, choices and goal. In level 1 there is one comparison matrix corresponds to pair-wise comparisons between 4 factors with respect to their role in contributing to the likelihood of crash.

Thus, the comparison matrix of level 1 has size of 4 by 4. Each choice is connected to each factor, and there are 6 road sections choices and 4 factors, then in general there will be 4 comparison matrices at level 2 with respect to the four factors. Each of these matrices has size 6 by 6. The analysis result is presented in the next chapter of section 4.4.2.

Table 3.3 The fundamental scale of absolute numbers (T.L., Saaty,2008)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak/slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong/Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
8	Very Very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above none zero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	A reasonable assumption.
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

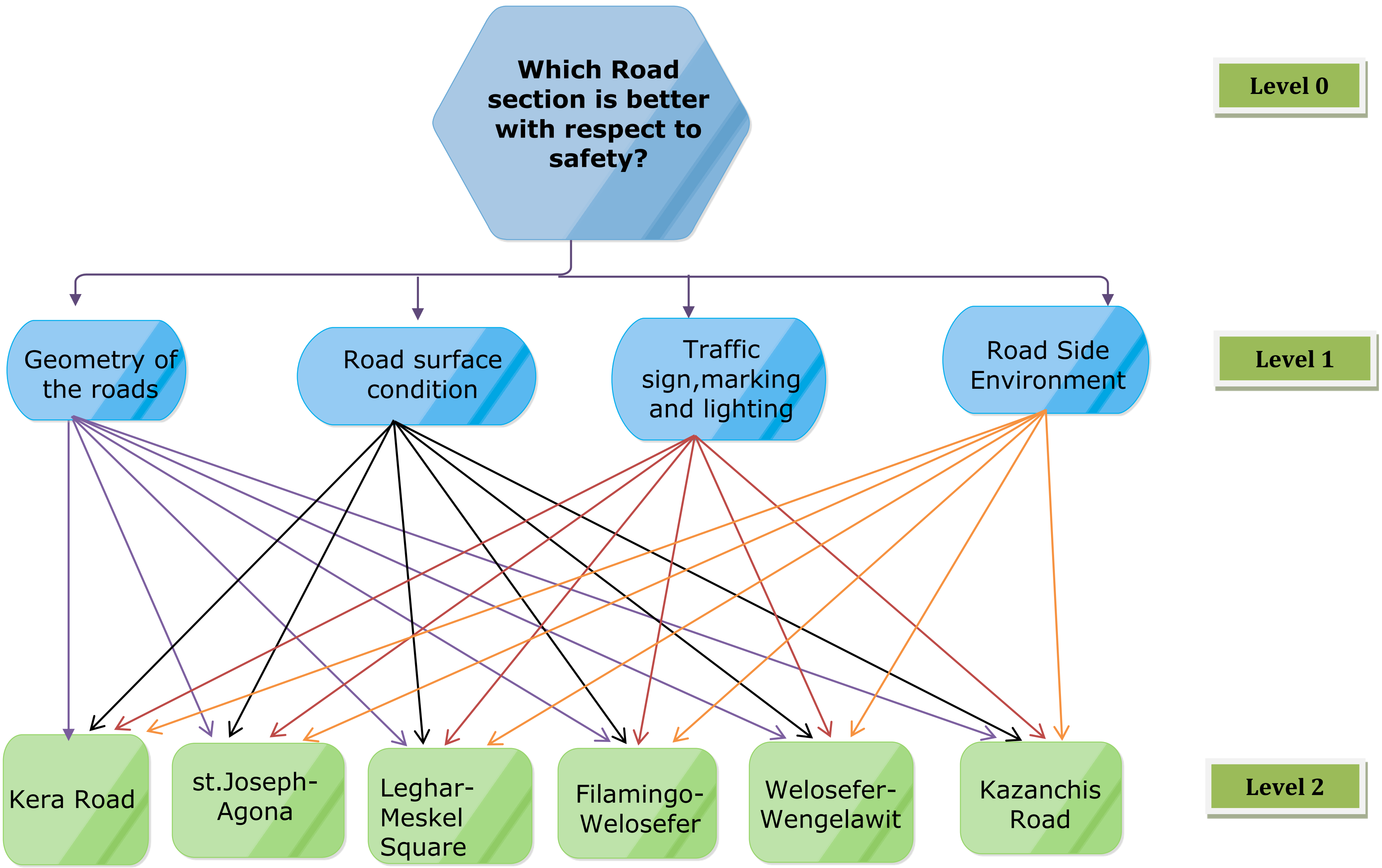

Figure 3.1 Hierarchical structures for selecting a better road section

3.7 Software and Equipment Used

The following software's and equipment were used to make the research well organized, tangible, clear and specific.

3.7.1 Softwares

- Edraw Max8.4 (to draw charts)
- Google Earth and Google Map(to identify locations)
- Easy Gps and Expert Gps(to import Gps data to google earth)

3.7.2 Equipments

- Tablet (for video recording)
- Digital camera (for taking pictures)
- Hand held GPS (for tracking coordinate points)
- Vehicle (to inspect the roads during the night)

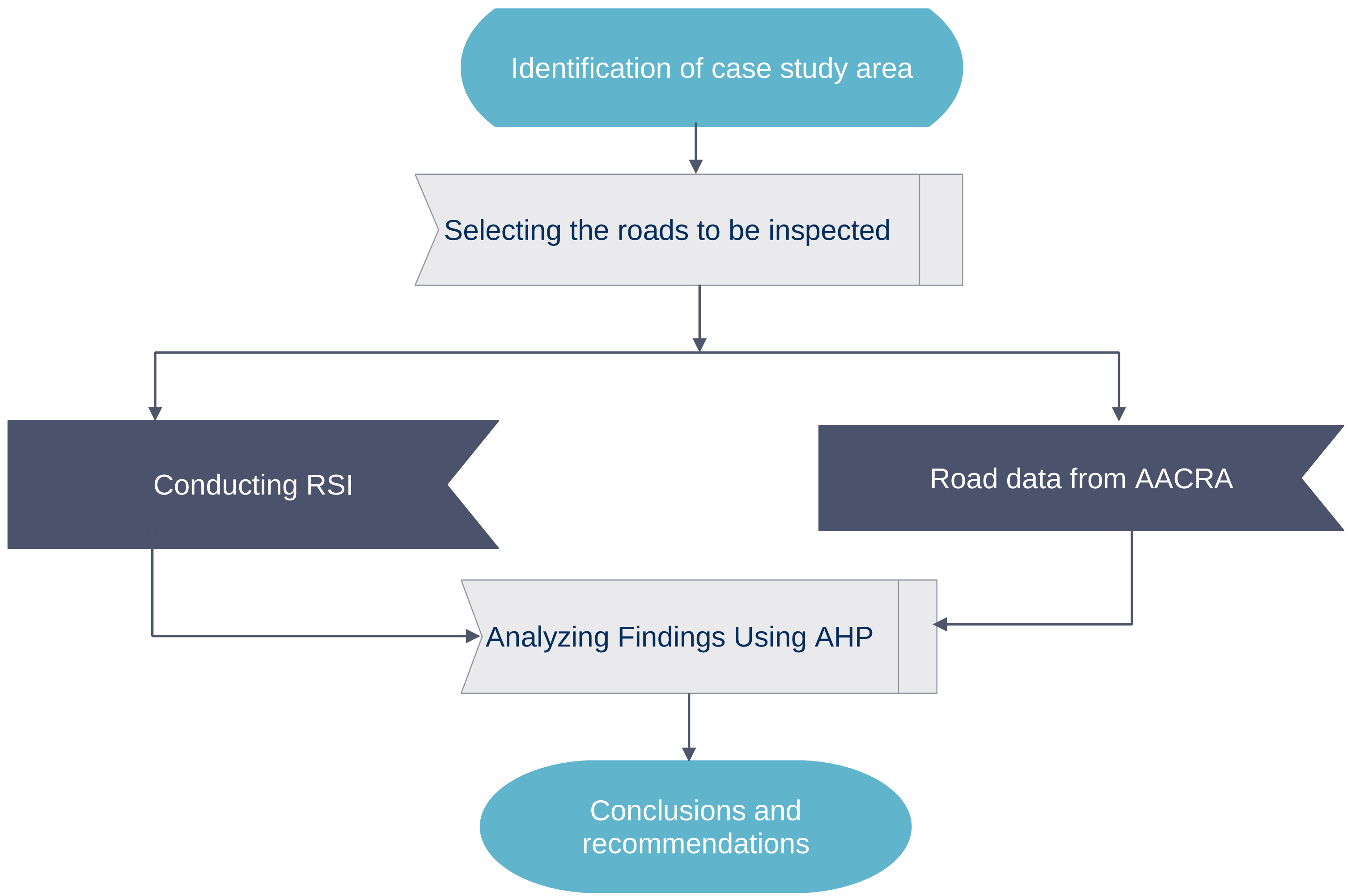

Figure 3.2 Summary of Methodology

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, the findings are analyzed in qualitative, quantitative and tabular forms. Accident data findings, condition of the roads and AHP analysis are presented in respective of section 4.2, 4.3 and 4.4

4.2Accident Distribution of Addis Ababa City and Selection of road sections

The primary aim of this research was to conduct RSI and analyze the result in order to identify the significant roadway components in contributing to road traffic accident in a proactive way.

For this research accident data were used as a supplement to identify the study area but, basically convenience sampling procedure were used. The data were organized based on the number of accident and severity of accident within the ten sub cities. Figure 4.1 and figure 4.2 shows the accident distribution. The figures indicate that, frequency of accident is increased year to year in all sub cities except lideta sub city in 2007EC. However, severe injuries of all sub-cities vary throughout each year.

From figure 4.1 Bole and kirkos sub-cities has highest traffic accident out of the ten sub cities located in the city but the scope of the research is to conduct the inspection in one sub city. A pilot study was done in both sub cities to check the availability of the required input data that will further help for selecting the road segments. Therefore, kirkos sub city is selected for the case study.

The daily recorded data of kirkos sub city is organized by taking the location name, type of crash, type of severity, light condition and road condition for simple accident data analysis in order to look up the accident distribution of the road segments located within the sub city.

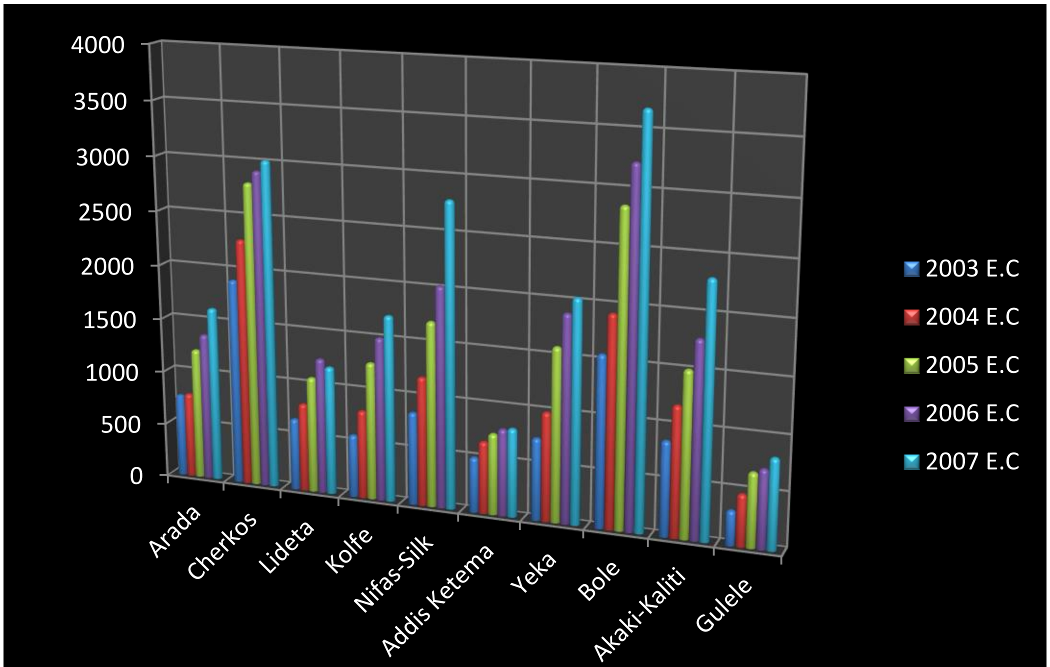

Figure 4.1 Accident distribution of subcities

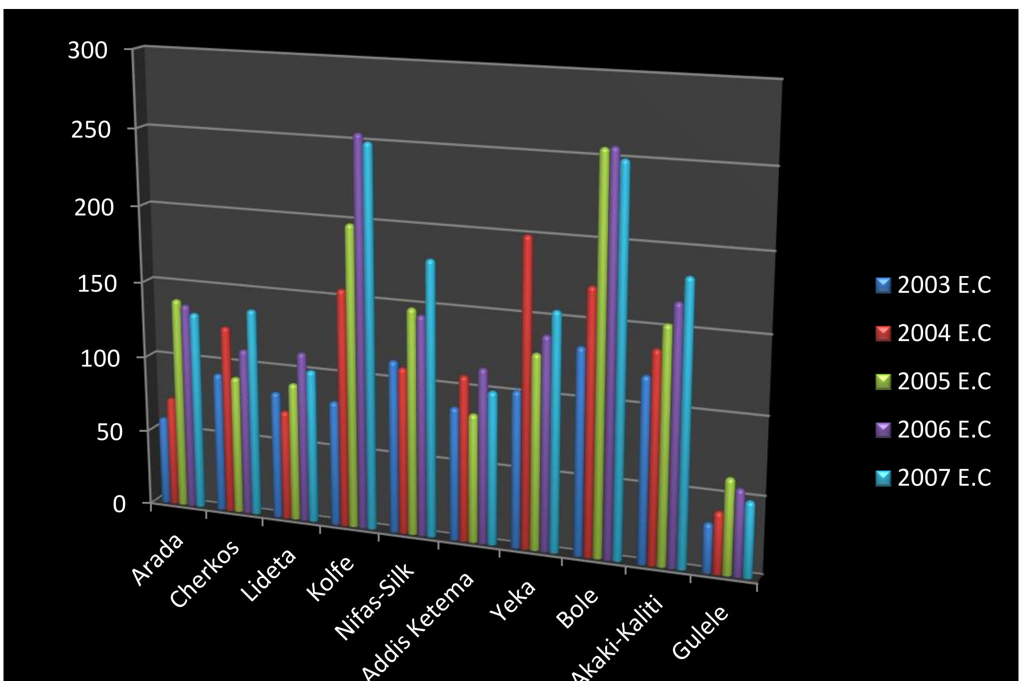

Figure 4.2 Severe injury distribution

4.2.1 Accident Density of the Road Sections

Accident densities (AD) describe the average annual number of Accident.it is calculated using the following formula.

AD= A/ L·t [A/ (km.yrs)]……………………………eq.1

Where: - A Number of accidents in t years [A]

L Length of road section [km]

t Period of time under review [years]

There were a total of eleven road sections with a total length of around 17.8 km. Only six road segments were selected for the inspection based on random sampling technique (see table 4.3).

No.	**Location name**
1	Kazanchis(development bank- kazanchis total)
2	welosefer-ibex-wengelawit-gotera
3	filamingo-olompiya-shoa supermarket
4	st. joseph-global-agona cinema
5	kera road(kera taxi station-bulgariya-kera gofa)
6	leghar-stadium
7	national theatre- fil wuha-national palace
8	meskel square road
9	meskel flower road
10	Au square –sarbet
11	urael –bambis

The selected roads covers a distance of more than 12.3km and the inspection were done on both sides of the roads. In addition intersections and roundabouts located within this road sections are not considered during the inspection.

Table 4.1 Accident Density of the road segments

Road Location Name	Frequency of accident			Distance in km.	Accident Densities (AD)
	2006	2007	2008		
Kazanchis(Development Bank- Hanan Bakery -Kazanchis Total)	216	311	301	1.00	276.00
Leghar-Stadium-Meskel square	148	342	422	1.5	202.67
Welosefer-Ibex-Wengelawit	237	357	274	2.2	131.52
Filamingo-Olompiya-Shoa Supermarket	206	276	243	2.1	115.08
Kera Road(Kera taxi station-Bulgariya-Kera)	185	289	196	2.8	79.76
St. joseph-Global-Agona Cinema	185	281	192	2.7	81.23

4.3 Condition of the road sections

The overall condition and available deficiencies of the road segments in terms of geometric condition, pavement surface condition, traffic sign, road marking, lighting and road side environment condition were identified and summarized in the tables.

4.3.1 Kazanchis Road (Development bank-Hanan Bakery-Kazanchis total)

This road section is sub arterial road. Even if it is a sub arterial road it has a large amount of traffic volume with a high accident density. In addition, it has good vertical and horizontal geometric alignment with good pavement surfacing. The observed results on this location are summarized in table 4.4 with their corresponding coordinates.

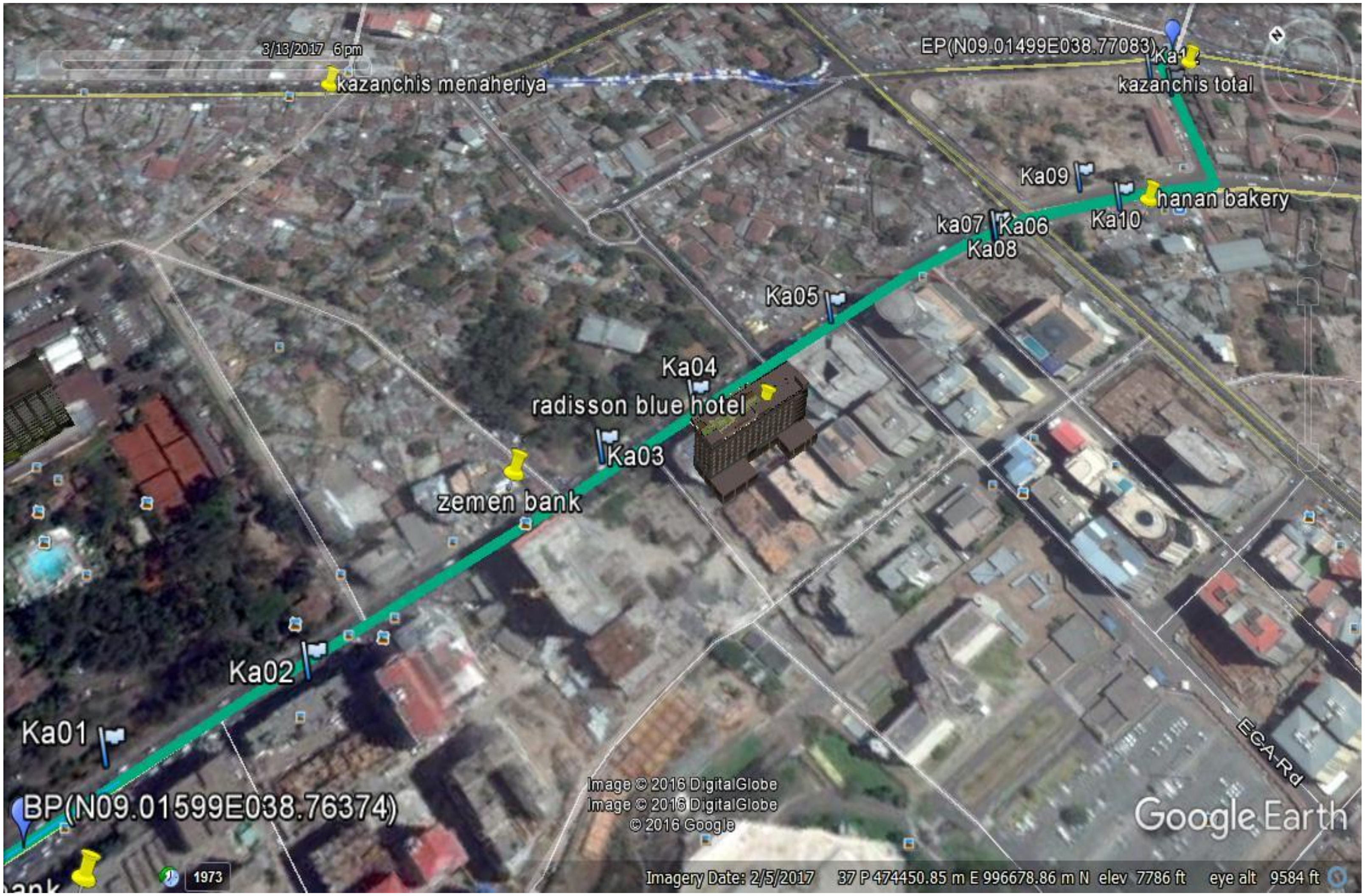

Figure4.3 Topographic views and coordinate points of Kazanchis road.

Table 4.2 RSI of Kazanchis Road(From Development Bank- Hanan Bakery-Kazanchis Total)

GPS dot name	Coordinates (Northing ,Easting)	Short Description of place
BP	37 P 474035 996538	Beginning point
Ka01	37 P 474129 996505	Ponding of water on the pavement surface
Ka01	37 P 474129 996505	Damaged traffic sign and lighting pole
Ka02	37 P 474319 996493	Blocked drain
Ka02	37 P 474319 996493	Reduced walkway due to parked vehicle.
Ka03	37 P 474380 996481	Missing gully cover
Ka04	37 P 474488 996468	Worn walk way
Ka05	37 P 474617 996437	Worn walkway
Ka06	37 P 474619 996438	Signal at the wrong position and not functional
Ka07	37 P 474619 996438	>> >> >>
Ka08	37 P 474693 996423	Reduced carriageway width due to parked public transportation
Ka09	37 P 474699 996394	Insufficient passenger and walk way facility, blocked drain
Ka10	37 P 474814 996427	Damaged sign, walkway occupied by parked vehicle
Ka11	37 P 474814 996427	Night time road side vendor, no lighting
EP	37 P 474818 996447	End point
Between GPS point Ka08 and Ka11 no road side lighting and there is no walk way The road has clearly visible road markings throughout the road section.		

As described in the table there are different deficiencies observed. There is no available passenger facility as a result the passengers are obliged to wait vehicles by standing on the carriage way. The other problem is the available walk ways are in poor conditions and are not comfortable for walking. From hanan bakery to Kazanchis total road section has no walk way. This makes the pedestrian safety at risk and traffic operation more difficult. The available parking space for taxis is not sufficient to give service for passengers due to this most of parked vehicles are reducing the driving lanes. Service areas and taxi stations are very close to each other as a result there is no sufficient space for passengers and pedestrians. Most of the available road side drainages are blocked by mud and has no ditch covers this make the water ponding on the pavement surface during rainy season. Some of the road side lightings are not functional.

There are also road side vendors on the driving lane and walk way both in day time and night time this may increase the risk for accident occurrence (See figures taken from site in the appendix). The risk of injury accidents was found to increase in darkness (Wanvik, 2009). To minimize the risk it is better to provide sufficient illumination.

4.3.2 Leghar-Stadium-Meskel square

This road section is known as with the street name of Ras Mekonen Street and Jomo Kenyatta Street. Compared to the other road section this road has good features with some deficiencies see table 4.5.

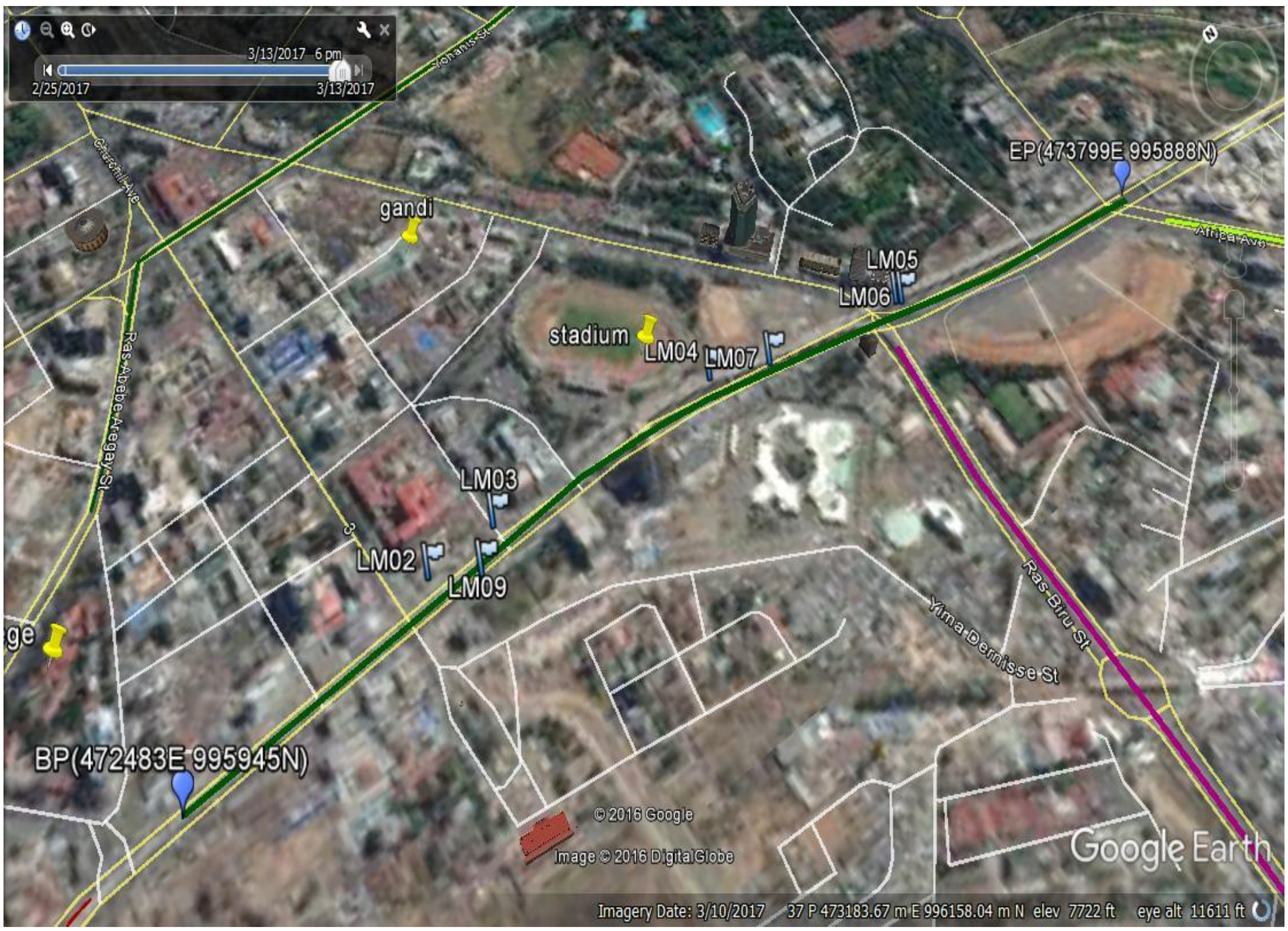

Figure 4.4 Topographic views and coordinate points of leghar-Meskel square road.

Table 4.3 RSI of Leghar – Stadium - Meskel Square Road

GPS dot name	Coordinate (Northing ,Easting)	Short description of place
BP(LM01)	37 P 472483 995945	Beginning point
LM01	37 P 472483 995945	Faded longitudinal marking
LM02	37 P 472812 995985	Faded pedestrian cross marking, unprotected utility line burrow
LM03	37 P 472904 995990	Dumped construction materials on walkway
LM04	37 P 473225 995986	Faded cross and longitudinal marking
LM05	37 P 473492 995926	Faded pedestrian cross marking
LM06	37 P 473498 995923	Un protected opened utility line manhole.
LM07	37 P 473301 995957	>> >> >>
LM08	37 P 473799 995888	>> >> >>
LM09	37 P 472865 995951	Insufficient passenger and parking facility
EP(LM08)	37 P 473799 995888	End point

The good things this road section consists that, it has wide parking bay at stadium this helps to park vehicles without reducing the driving lane and to provide safe service for passengers by preventing them from standing and wait transportation vehicles on driving lane, the alignment of the road has good visibility, good sidewalks and good night time visibility. However some deficiencies were identified during the observation. There are faded longitudinal and pedestrian cross markings, dumped construction materials on the pedestrian walk way that obstruct the pedestrian movement and opened utility line manholes on the walk way without protection or warning sign to the road users this may create danger during night time.

4.3.3 Welosefer-Ibex-Wengelawit

This road section is known with the street name called Ethio-Chinese friendship road. It has eight horizontal curves with a minimum curvature radius of 400m and maximum radius of 3200. The minimum grade of the road is -0.3% and maximum grade -7.9%. Therefore, the vertical road grades are less than 10% and its good regard to safety.

Figure 4.5 Topographic view of welosefer-wengelawit road

Table 4.4 RSI of Welosefer – Ibex – Wongelawit Road

GPS dot name	Coordinate (Easting, Northing)	Short description of place
BP	37 P 475092 993927	Beginning point
WW01	37 P 474797 994400	Walk way obstructed by construction debris
WW02	37 P 475035 993802	Blocked drains
WW03 & BP	37 P 475008 993702 & 37 P 474917 994252	No road side lighting
WW05	37 P 474904 993546	Construction site fence reduced width of walkway
WW06	37 P 474750 993361	Damaged road lighting and trashes on the walk way.
WW07	37 P 474145 992821	Wrong position of traffic sign
EP&WW08	37 P 473910 992617 & 37 P 474027 992706	No road side lighting
WW09	37 P 473969 992668	Overhanging branch of trees, Construction site fence reduce walkway width
WW10	37 P 475042 993802	Construction site fence block the walkway and reduce carriageway width
EP	37 P 473910 992617	End point
Most of road side drains are blocked by dirt.		
No longitudinal road marking throughout the road section		

The identified problems on most of the section of this road are pedestrian walk ways are blocked by construction fence, dumped construction materials, and wastes. The other problems are the road has no longitudinal road marking both center lines and edge lines to delineate the traffic, there are vegetation on the walk way that hinder the movement of pedestrians on the walk way, incorrect placement and damaged traffic signs are available on this road, almost all of the ditches are filled with dirt and mud finally at some location there were no road side lighting. (See figures in the appendix)

4.3.4 Filamingo-Olompiya-Shoa supermarket

This road is known as Africa Avenue or Airport road. It has five horizontal curves with a minimum radius of 500m and maximum radius of 1040m. The maximum and minimum vertical grade of the road is -6.5% and 0.6% respectively. These shows the geometrical alignment of this section is good.

Figure 4.6 Topographic views and coordinate points of filamingo-welosefer road.

Table 4.5RSI of the road from Filamingo – Olompiya - Shoa Supermarket

GPS dot name	Coordinate (Easting, Northing)	Short description of place
BP	37 P 473887 995783	Beginning point
FS01	37 P 474038 995624	Damaged Traffic sign, blocked gully
FS02	37 P 474218 995428	Faded longitudinal road marking
b/nFS03&FS04	37 P 474552 994891& 37 P 474259 995407	There is no delineation and lighting at the underpass.
FS05	37 P 474795 994400	Traffic sign obstructed by road side vegetation
FS06	37 P 474925 994225	sign obstructed by road side vegetation
b/n FS07&EP	37 P 474934 994182 & 37 P 47509 993927	Road side lightings are not functional
EP	37 P 475092 993927	End point
Faded longitudinal road marking throughout the entire road section		

The overall visibility, pavement condition, traffic sign and road side environment of the road is in good condition compared to other roads. However, there are still problems regarding pedestrian refugees, traffic signs, marking and delineations. There is damaged traffic sign, the bough and leaves of road side vegetation reduce the visibility of traffic signs, almost all of the longitudinal markings are fade up and it's not clearly visible, there is no delineation during night time at location point of FS03 and some of the road side lightings are not functional. The effects of road lighting are greater for more serious accidents. The effects are also greater for pedestrian accidents and for accidents at junctions than for other accidents (Elvik Rune et al.,2009). The available median refuge around filamingo is smaller compared to the available pedestrian road users. There is high number of pedestrians especially during peak hour.

4.3.5 Kera road (Mexico kera taxi station-Bulgaria-kera)

The street name from Mexico, kera taxi station to Bulgaria is called Mozambique Street and from Bulgaria to kera abattoirs called Tanzania street. The drainage inlets are filled by dirt and mud, there are also uncovered ditches. There is no longitudinal road markings, the available traffic signs are under poor condition, most of the road side lightings are not functional and the road is not clearly visible during night time, there are cracks on the pavement surface, the medians and islands are damaged (see figures in the appendix). There is a high number of pedestrian at Mexico kera taxi station and kera abattoirs; however the available refuge areas at this location is not sufficient to accommodate the pedestrians crossing the road. The result from the field investigation is summarized and presented under table 4.8.

Figure 4.7 Topographic views and coordinate points of Kera road.

Table 4.6 RSI of Kera Road(From Mexico kera taxi station–Bulgaria–Kera Abattoirs)

GPS dot name	Coordinate (Northing ,Easting)	Short description of place
BP	37 P 472023 995776	Beginning point
KE04	37 P 472265 993469	Excavated material on the walkway, blocked drain
KE05	37 P 472253 993580	pavement crack, blocked drain, worn walk way, damaged island kerb
KE06	37 P 472201 993842	Missing drain cover and filled by dirt
KE07	37 P 472205 994008	Ponding of water, worn walk way
KE08	37 P 472207 994017	>> >>
KE09	37 P 472179 994219	Faded pedestrian cross marking and damaged median kerb
KE10	37 P 472160 994283	Blocked and uncovered drain ,construction debris on pedestrian walkway
KE11	37 P 472170 994360	Improper drainage cover, damaged median kerb
KE12	37 P 472114 994691	Fence of construction site reduce pedestrian walkway, construction debris on walk way
KE13	37 P 472099 994851	Damaged traffic sign
KE14	37 P 472074 995102	Blocked drainage and walkway blocked by construction debris
EP	37 P 472269 993150	No pedestrian cross marking on left side of the road in the direction towards Mexico, pavement crack, damaged median kerb, blocked drain.
EP	37 P 472269 993150	End point
There is no longitudinal road marking and advance warning signs at intersections throughout the whole road section.		
From coordinate pt.KE01-KE02(37 P 472201 994016;37 P 472264 993155) no road lighting, the remaining available road lightings are not sufficiently illuminated		

4.3.6 St. joseph School-Global-Agona Cinema

It is also known as Sierra Leone Street. This section of the road consists of eight horizontal curves with minimum and maximum radius of 300m and 1000m respectively.-3.6% and -1.3% is the maximum and minimum vertical grade of the road segment.

Figure 4.8 Topographic views and coordinate points of St. Joseph- Agona road.

The pavement of this road section has depression and there are also ponding of water on the surface of the pavement. The road is not sufficiently illuminated at night. But compared to the other road section this road has good informative and warning sign at intersections and railway crossings. The deficiencies on this road section are summarized in table 4.9.

Table 4.7 RSI of the road from St. Joseph School – Global- Agona Cinema)

GPS dot name	Coordinate (Northing ,Easting)	Short description of place
BP	37 P 473438 995873	Beginning point
SA01	37 P 473429 995804	Faded cross marking
SA02	37 P 473410 995820	Damaged pedestrian walkway, damaged sign
SA03	37 P 473407 995765	Ponding of water on the pavement
SA04	37 P 473407 995764	Pavement depression
SA05	37 P 473402 995582	Road side debris on walk way, traffic sign obstructed by trees
SA06	37 P 473375 995449	no walkway, pavement deterioration
SA07	37 P 473383 995170	damaged traffic sign, signs obstructed by trees, faded cross marking, old road cross marking not removed ,damaged walkway
SA08	37 P 473463 993858	Excavated material on walk way, damaged walkway
SA09	37 P 473442 995439	No walkway
SA10	37 P 473444 995875	Fence of construction site reduce pedestrian walkway, road side debris on walk way
SA12	37 P 473420 993636	Damaged guard rail and hazardous object in the median
b/n SA11-SA12	37 P 473388 995257&37 P 473420 993636	No road side lighting
b/n SA13-SA14	37 P 473441 993657 & 37 P 473463 993895	>> >>
b/n SA15-SA16	37 P 473381 994586 & 37 P 473417 995337	>> >>
EP	37 P 473494 993305	End point
There is no longitudinal road marking throughout the road section		

4.4Quantitative Analysis

Using the prepared excel template, the significant factors that contribute for accident occurence on the selected road sections were analyazed and the results are presented on the following section.

The value of the pair wise comparisons is taken from table 3.2 but as mentioned in the methodology the judgment values taken from the questioners filled by focus groups. For the factors that may cause high safety risk gets the highest value and the least value is given for the factors that may contribute to less risk. For all road section the four major road components which are Geometric Condition (GC); Road Surface Condition (RSC); Traffic Sign, Road marking and Lighting (TSRML) and Road Side Environment (RSE) are considered for the analysis.

4.4.1 The significant safety factor for each road section

4.4.1.1 Kazanchis Road (Development bank-Hanan Bakery-Kazanchis total)

The pairwise comparisons were done using the model developed in a spreadsheet. The judgment value is taken from the questionnaire filled by focus group. The final judgment value is rounded to the nearest upper or lower value. Consistency ratio (CR) is determined to check the consistency of the judgment. Table 3.2 describes the meaning of each judgment value. If the consistency ratio is smaller or equal to 0.1 (10%) the inconsistency is acceptable. If the consistency ratio is greater than 10% the judgment needs to be revised (Tiantaphyllou and H.Mann, 1995). In addition, pictures taken from the field investigation that shows the condition of the roads is attached in appendix-3 for each road segment in order to show the road conditions. Therefore, the square matrix of the judgment for this road section is arranged as follows.

	GC	RSC	TSRML	RSE
GC	1	3	5	4
RSC	1/3	1	4	3
TSRML	1/5	1/4	1	1/2
RSE	1/4	1/3	2	1

In AHP analysis of pairwise comparison, the diagonal elements of the matrix are always 1 and only need to fill up the upper triangular matrix. In this case the geometric mean is used to aggregate the result of the focus group. In the above pairwise comparison, the meaning of each value is described below.

Comparing GC with RSC, GC moderately affect road safety than RSC, thus the judgment value of 3 is put in column 2 row 1. Similarly comparing GC with TSRML, GC strongly affect than TSRML, thus 5 is put in column 3 row 1. Comparing GC with RSE, GC has moderate plus effect on the road safety, thus 4 is put in column 4 row 1.

Comparing RSC with TSRML, RSC has moderate plus effect than TSRML, thus 4 is put in column 3 row 2. Comparing RSC with RSE, RSC has moderate effect than RSE, thus 3 is put in column 4 row 2.

Comparing TSRML with RSE, RSE is slightly affect than TSRML, thus 1/2 is put in column 4 row 3.

To fill the lower triangular matrix, the reciprocal values of the upper diagonal are used. The overall steps used in the spread sheets are attached in appendix-2

2. All columns are summed up.

	GC	RSC	TSRML	RSE
GC	1	3	5	4
RSC	1/3	1	4	3
TSRML	1/5	1/4	1	½
RSE	1/4	1/3	2	1
Sum	1.783	4.583	12	8.5

3. Each cell in the column divided by sum of its own column

	GC	RSC	TSRML	RSE
GC	0.56075	0.65	0.416667	0.47
RSC	0.18692	0.21818	0.333333	0.352941176
TSRML	0.11215	0.05455	0.083333	0.058823529
RSE	0.14019	0.07273	0.166667	0.117647059
Sum	1	1	1	1

4. The priority vector (normalized right Eigen vector) calculated as

Priority vector

$$Pv=(\sum \text{Each rows})/n= \begin{pmatrix} 0.525637 \\ 0.272843 \\ 0.077213 \\ 0.124307 \end{pmatrix}$$

Then value of eigen vector and eigen values were calculated .The normalized principal/priority eigen vector is

$$\begin{pmatrix} 0.52564 \\ 0.27284 \\ 0.07721 \\ 0.12431 \end{pmatrix}$$

Percentage of each factors

GC	RSC	TSRML	RSE
53%	27%	8%	12%

This is not the final result, because the judgment is further checked for its consistency weather the judgment is rational or not. So the consistency is checked using consistency ratio (CR) and it is calculated as below.

Before determining the CR the principal Eigen value of the previous matrix is determined to obtain the consistency index (CI).

λ_{max}=(∑each columns of square matrix *priority vector)

λ_{max}=(1.783*0.52564)+(4.583*0.27284)+(12*0.07721)+(8.5*0.12431)=4.53

λ_{max}=**4.17** & the size of comparison matrix is **n=4** thus the consistency index is

CI=(λ_{max}-n)/n-1

CI =4.17-4/4-1=0.057

We compare CI with RI to know the CR. RI value is obtained from table 3.2 for n=4; RI=0.9

CR=CI/RI

CR =0.057/0.9=**0.06336/6.34% <10%** **Acceptable!**

Similar judgment and analysis method were used for other road sections.

As shown in the result of percentage of each factors above, Geometric condition takes more than half percentage of other factors and it becomes the primary significant factor for this road section followed by pavement surface condition, road side environment and traffic sign, road marking and lighting.

The focus groups suggest that, the cross section of the road section highly affect the safety of the road users. In the road section there are no pedestrian walk way and no sufficient pedestrian refuges during crossing the road makes road users at risk. The other safety factor is road surface condition. When the road surface condition is good, most road users experience high speed driving so that this becomes another problem occurred on the roads.

For instance, on this road section there were no pedestrian walkway from hanan bakery to total, no passengers and parking facility. Therefore Service areas and taxi stations are very close to each other. There are also road side vendors during day and night that obstruct pedestrian movement. So, some of the defect described here makes the cross section of the road which is included in the road geometry condition makes to take the highest proportion and it has high impact regarding safety.

4.4.1.2 Leghar-Stadium-Meskel square

The judgment square matrix for this section of the road is arranged as follows. Judgment value is given with similar method like the above road section.

	GC	RSC	TSRML	RSE
GC	1	3	5	3
RSC	1/3	1	4	3
TSRML	1/5	1/4	1	1/3
RSE	1/3	1/3	3	1

The determined priority vector is

$$\begin{pmatrix} 0.495992 \\ 0.278384 \\ 0.071016 \\ 0.154608 \end{pmatrix}$$

In order to check the consistency λ_{max} and CI is calculated and the result is **λ_{max}=4.26**&**CI=0.086**

Then CR=<u>0.09585/9.585%</u> <10% acceptable!

Percentage of each factors

GC	RSC	TSRML	RSE
50%	28%	7%	15%

From the result geometric condition takes half percentage of the other factors. Road surface condition takes more than quarter of the total factors. The other two factors have less proportion. Therefore the significant factor for this road section also geometric condition. On this road section there is wide road lane at meskel square and it makes pedestrian safety at risk during crossing the road. In addition, the pavement surface is good and there is high speed driving. This may increase the risk of the road users.

4.4.1.3 Welosefer-Ibex-Wengelawit

The square matrix of the judgment is

	GC	RSC	TSRML	RSE
GC	1	3	1/4	1/5
RSC	1/3	1	1/5	1/6
TSRML	4	5	1	1/2
RSE	5	6	2	1

The determined priority vector is

$$\begin{pmatrix} 0.119095 \\ 0.061545 \\ 0.319536 \\ 0.499824 \end{pmatrix}$$

With the value of λ_{max}**=4.19& CI=0.063078; CR=0.070086/7.01 %< 10% Acceptable!**

Percentage of each factors

GC	RSC	TSRML	RSE
12%	6%	32%	50%

On this road section, road side environment is the major accident contribution factor followed by traffic sign, road marking and lighting.

Most of the available walkway blocked by construction fences and dumped construction materials. No road lightings at night, no road marking and damaged traffic signs. Due to this reason the above two factors are more significant than others.

4.4.1.4 Filamingo – Olompiya - Shoa supermarket

The square matrix of the judgment is

	GC	RSC	TSRML	RSE
GC	1	2	5	4
RSC	1/2	1	4	5
TSRML	1/5	1/4	1	2
RSE	1/4	1/5	1/2	1

The determined priority vector is $\begin{pmatrix} 0.47551 \\ 0.33597 \\ 0.10923 \\ 0.07928 \end{pmatrix}$

In order to check the consistency λ_{max} and CI is calculated and the result is **λ_{max}=4.18& CI=0.06156**

Then **CR=<u>0.0684/6.84%</u> <10% Acceptable!**

Percentage of each factors

GC	RSC	TSRML	RSE
48%	34%	11%	8%

As shown above; geometric condition has a largest proportion than other factors. Therefore, it becomes the significant factor for this road section followed by road surface condition.

4.4.1.5 Kera Road (Mexico, kera taxi station-Bulgaria-kera)

For this section of road the judgment square matrix arranged as follows.

	GC	RSC	TSRML	RSE
GC	1	4	3	3
RSC	1/4	1	1/4	1/3
TSRML	1/3	4	1	1/2
RSE	1/3	3	2	1

The determined priority vector is

$$\begin{pmatrix} 0.48894 \\ 0.08068 \\ 0.19267 \\ 0.2377 \end{pmatrix}$$

Percentage of each factors

GC	RSC	TSRML	RSE
49%	8%	19%	24%

From the above result geometric condition takes 49%, road surface condition takes 8%, traffic sign, road marking and lighting takes 19% and road side environment takes 24% of the total result.

To check the consistency of the judgment λ_{max} and CI is calculated and the result is **λ_{max}=4.26 & CI=0.0861**

Then **CR=<u>0.09572/9.572% <10% </u>**the judgment is consistent and Acceptable!

4.4.1.6 St. joseph School-Global-Agona Cinema

For this road the judgment of square matrix arranged as follows.

	GC	RSC	TSRML	RSE
GC	1	2	1/3	1/4
RSC	1/2	1	1/4	1/4
TSRML	3	4	1	1/2
RSE	4	4	2	1

The determined priority vector is

$$\begin{pmatrix} 0.12937 \\ 0.08613 \\ 0.31141 \\ 0.47309 \end{pmatrix}$$

Percentage of each factors

GC	RSC	TSRML	RSE
13%	9%	31%	47%

With the value of λ_{max}=4.11and CI=0.0364 the consistency ratio becomes CR=**0.04041/4.04%<10%**The judgment is consistent.

The result indicates; road side environment is the primary significant factor in contributing to traffic accident.

Generally, the focus groups give more emphasis on cross section of the roads and pavement surface condition. Lane width and median width has highest effect. For instance the road width at meskel square is very wide, median width for pedestrian refuge at bole road is very narrow with respect to the number of pedestrians that cross the road and in some sections of Kazanchis road there is no pedestrian walk way. Pavement surface condition of most road section is under good condition, however, the focus group suggests that this makes the road users to drive in excess speed and create higher risk. Therefore those road elements get high attention based on the focus groups judgment.

4.4.2 Prioritizing the road sections

Two levels of AHP analysis is done to identify the better road section based on the four major factors among the six road segments. This helps to know which road has good road way facilities and which road require more attention with respect to each other in order to provide solution.

For the first level of AHP analysis; the four major factors are compared depends on their role in contributing to the likelihood of crash. Similar to the above analysis the score value is taken from the group judgment and the lowest value is used for factor that has less effect on safety and vice versa.

The pair wise comparison of level-1 judgment matrix for the factors is arranged as follow:-

Criteria	GC	RSC	TSRML	RSE
GC	1	2	1/4	1/5
RSC	1/2	1	1/4	1/5
TSRML	4	4	1	1/3
RSE	5	5	3	1

The priority vector is $\begin{pmatrix} \mathbf{0.108211} \\ \mathbf{0.075473} \\ \mathbf{0.282204} \\ \mathbf{0.534112} \end{pmatrix}$

λ_{max}=4.24, CI=0.079202, CR=8.8% <10% Acceptable!

The result of level-1 analysis indicate road side environment and signs, markings and lighting takes the major part where as pavement surface and geometry has less proportion. Therefore road side environment is the major factor in contributing for the likelihood of crash followed by traffic sign, road marking and lighting, geometric condition and pavement condition.

Level 2 judgment matrix is calculated for all road segments with respect to each of the above factors.

Paired comparison matrix with respect to **Geometry**

choices	LM	FS	WW	SA	KE	Ka	Priority Vector
LM	1	1/2	1/3	1/3	1/4	1/3	**5.61%**
FS	2	1	1/2	1/3	1/4	1/3	**7.76%**
WW	3	2	1	3	1/3	2	**21.09%**
SA	3	3	1/3	1	1/3	2	**16.28%**
KE	4	4	3	3	1	2	**34.65%**
Ka	3	3	1/2	1/2	1/2	1	**14.62%**

λ_{max}=6.51, CI=0.102703, CR=8.28% <10% Acceptable!

LM- Leghar – Meskel square

FS- Filamingo-Shoashoping

WW- Welosefer-Wengelawit

SA-St.joseph school-Agona cinema

KE-Kera road

KA- Kazanchis road

Paired comparison matrix with respect to **pavement surface**

choices	LM	FS	WW	SA	KE	Ka	Priority Vector
LM	1	1	1/2	1/3	1/4	1/2	**7.34%**
FS	1	1	1/2	1/3	1/4	1/2	**7.34%**
WW	2	2	1	1/2	1/2	2	**16.27%**
SA	3	3	2	1	1/3	2	**21.89%**
KE	4	4	2	3	1	2	**34.26%**
Ka	2	2	1/2	1/2	1/2	1	**12.91%**

λ_{max}=6.21, CI=0.041824, CR=3.37% <10% Acceptable!

Paired comparison matrix with respect to **traffic sign, road marking and lighting**

choices	LM	FS	WW	SA	KE	Ka	Priority Vector
LM	1	1/2	1/3	1/3	1/5	1/3	**5.39%**
FS	2	1	1/2	1/2	1/4	2	**10.52%**
WW	3	2	1	1/2	1/3	3	**16.17%**
SA	3	2	2	1	1/3	3	**19.96%**
KE	5	4	3	3	1	4	**39.41%**
Ka	3	1/2	1/3	1/3	1/4	1	**8.54%**

λ_{max}=6.33, CI=0.06614, CR=5.33% <10% Acceptable!

Paired comparison matrix with respect to **road side environment**

choices	LM	FS	WW	SA	KE	Ka	Priority Vector
LM	1	2	1/5	1/5	1/5	1/4	**5.45%**
FS	1/2	1	1/5	1/5	1/4	1/3	**4.49%**
WW	5	5	1	3	3	3	**37.45%**
SA	5	5	1/3	1	2	2	**22.31%**
KE	5	4	1/3	1/2	1	2	**17.54%**
Ka	4	3	1/3	1/2	1/2	1	**12.75%**

λ_{max}=6.43, CI=0.086625, CR=6.99% <10% Acceptable!

The overall composite weight of each alternative choice (road sections) based on the weight of level 1 and level 2 is computed below

CW=Pv of the criteria***Pv** of the road sections with respect to each criteria

CW:-Composite Weight Pv:-Priority Vector

For example, LM=0.108211(5.61%) +0.075473(7.34%) +0.282204(5.39%) +0.534112(5.45%)

=**5.59%**

The composite weight of the other five road section is computed similar to the above example and the result is compiled in the following table. The weights are the priority vector under level-1 analysis which is described in the above analysis of section 4.4.2.

	GC	RSC	TSRML	RSE	Composite Weight
Weight	**0.108211233**	**0.075473**	**0.282204**	**0.534112**	
LM	5.61%	7.34%	5.39%	5.45%	**5.59%**
FS	7.76%	7.34%	10.52%	4.49%	**6.76%**
WW	21.09%	16.27%	16.17%	37.45%	**28.08%**
SA	16.28%	21.89%	19.96%	22.31%	**20.97%**
KE	34.65%	34.26%	39.41%	17.54%	**26.82%**
Ka	14.62%	12.91%	8.54%	12.75%	**11.78%**

Road side environment contribute more than half of the other factors. Next to road side environment more than the quarter percentage of the factors holds by traffic sign, road marking and lightings.

The overall consistency of the hierarchy is computed by summing for all levels with weighted consistency index (CI) in the nominator and weighted random consistency index (RI) in the denominator.

$$\overline{CR} = \frac{\sum w_i CI_i}{\sum w_i RI_i} = 7.4\ \% < 10\%\ \text{Acceptable!}$$

$\overline{CR}$-Weighted consistency ratio

w_i- weight of each factor

CI_i–Consistency index of the road segment with respect to each factor

RI_i-Random consistency index: for n=6, RI=1.24

Based on the weighted consistency ratio result the judgment of the analysis is within acceptable range of inconsistency.

To meet the goal shown in figure 3.1 the above AHP analysis were done. In level one analysis the result indicates that the significant factors are TSRML and RSE. However, to select the better road section each road sections are analyzed with respect to the four factors. Finally, the composite weight of the analysis result show that the road sections between welosefer-wengelawit followed by kera road and st. joseph- agona road section has a highest composite weight of 28.08%, 26.82% and 20.97% respectively than other road sections.

Comparison of analysis result and actual condition		
Road Location Name	**No. of accident**	**Composite Weight**
Kazanchis(Development Bank- Hanan Bakery -Kazanchis Total)	828	11.78%
Leghar-Stadium-Meskel square	912	5.59%
Welosefer-Ibex-Wengelawit	868	28.08%
Filamingo-Olompiya-Shoa Supermarket	725	6.76%
Kera Road(Kera taxi station-Bulgariya-Kera)	670	26.82%
St. joseph-Global-Agona Cinema	658	20.97%

Based on the analysis result roads with the highest composite weight is highly prone to accident occurrence and the roads with lowest composite weight has less effect. However, when the result is compared with the actual condition as shown in the above table, the roads with lowest composite weight has highest number of accident. Even if the analysis was done by considering only four factors, there are still other additional factors that affect the road safety. Therefore, roads with good facilities does not mean completely safe and has no accident.

Generally, the prepared template is helpful in providing the quantitative result for qualitative findings of RSI in order to make rational decisions. Moreover the method is suitable to prioritize which roads require more attention especially during budget restriction.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Safety is a complex issue and it depends on different factors due to that it's difficult to provide a single solution that can completely solve an identified road safety problem. From the result of the analysis the following conclusions are drawn.

- The available walk ways are worn out and some are damaged, thus are not comfortable for road users. In most of the road sections there are dumped construction materials and wastes on the pedestrian walk way. The construction site fence also constructed by reducing and blocking the walk way.
- The focus groups suggest smooth pavement surface increase the risk of accident occurrence by creating excess speeding. Narrow pedestrian refuges also makes pedestrian at risk during crossing the roads.
- The other common problem is the available longitudinal road markings are faded up and totally invisible; traffic signs are not properly located and some are damaged.
- Both the qualitative and quantitative result shows the condition of road side environment, the usage and availability of traffic signs, road markings and road side lightings are very poor.
- On this research pair wise comparison of AHP analysis were developed to prioritize road sections and for identification of significant road factors that may contribute for accident. This analysis can be applicable for any type of roads in order to quantify the effect of road components.
- Finally, It was found that using AHP analysis two major things are obtained, firstly the main deficiencies on each road sections is easily identified and second, it helps to which road component is the priority will be given in order to provide treatment or maintenance during limitation of budget.

5.2 Recommendations

Based on the study findings and result the following points and future research areas are recommended.

- From the result of this research geometrical alignment and pavement condition of almost all roads is not subjected to change with in short period of time. However, condition of the other road components such as traffic signs, road markings, road side lightings, road side drainages and road side environments has a higher probability for changes within short period of time as a result I recommend the concerned body to check the conditions and functionality of those road components with regular time interval in order to provide safe road infrastructure service.
- Traffic signs and road markings are not provided on some road sections. Some of the available signs and markings also not clearly visible, this indicates the usage of those road components are under estimated. Therefore, it's recommended for road authorities to provide those road components and check their conditions.
- There are construction fences and dumped construction materials on road side that obstruct the movement of road users. I recommend the concerned body to take action in order to create safe road side environment.
- Often comprehensive accident data are not available. Even if accident data is available, it is difficult to analyze the data due to its poor quality. As a result RSA/RSI doesn't require accident data so that I recommend the road authorities to implement RSA and RSI in their projects from the inception up to service life of the roads in order to provide a proactive measure to prevent the likelihood of crashes.
- Using similar method on this research, I recommend future research on identifying accident contributing factors of the roads for major intersections in the city of Addis Ababa and rural roads of the country.

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APPENDICES

Appendix-1 Questioner and Field investigation form

ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Master's program in road and transport engineering stream

Dear Respondent

First and foremost, I would like to express my gratitude in advance for your cooperation to complete the questionnaire and sparing of your precious time.

General Instruction

The survey should be completed by the person(s) with knowledge of road safety activities. The purpose of this survey is for the study entitled, **AHP Application for analysis of road safety inspection (RSI);** a case study on selected road sections of Addis Ababa city. There are six selected road sections and the rating will be given independently for each roads. The intersections located within the listed below road sections are not considered for evaluation:-

a) Leghar – Stadium-Meskel square
b) Filamingo-Olompiya-Shoa Shopping
c) Welosefer-Ibex-Wengelawit
d) St.joseph school-Global-Agona cinema
e) Kera road (Mexico, Kera taxi station-Bulgariya-Kera Abattoirs)
f) Kazanchis road (Development Bank-Hanan Bakery-Kazanchis total)

The rating will be given from 1-9.

1-no effect	5- Strong	9- Extreme effect
2- Weak/slight	6- Strong plus	
3- Moderate	7- Very strong	
4- Moderate plus	8- Very Very strong	

Criteria	If yes /no, rate the effect of each sub-criteria on safety										
1.Road Geometry (Alignment, Cross section and Drainage)	Yes	No	1	2	3	4	5	6	7	8	9
1.1 Is the alignment of the road clearly visible along the entire section without any obstructions?											
1.2 Are the cross section dimensions (i.e lane width, median width & walk way width) suitable for the function of the road?											
1.3 Have the needs of public transport and its users been taken into consideration?											
1.4 Is there sufficient cross fall and longitudinal fall?											
1.5 Is the drainage system suitable for the road and surroundings?											
1.6 Are there uncovered or deep road side ditches?											
2. Road surface condition											
2.1 Is Condition of the road surface in (ruts, cracks and potholes)?											
2.2 Are there changes in surface type (e.g., pavement ends) free of drop-offs/poor transitions?											
2.3 Is the pavement free of areas where ponding or sheet flow of water occurs resulting in safety problems?											
2.4 Is the pavement free of loose aggregate/gravel that may cause safety problems?											
3. Traffic signs, markings and lighting											
3.1 Are the traffic signs clearly visible and located properly without obstructing the view? (Not blocked by vegetation, parked vehicles, or the like, lettering size).											
3.2 Are signs retro reflecting or are they illuminated at night? (In daylight and darkness)											
3.3 Are the markings likely to be effective under all expected conditions (day, night, wet, and dry)?											
3.5 Is all lighting operating satisfactorily?											
4. Road side environment											
4.1 Are pedestrian facilities of a safe design (consideration of sufficient queuing and refuge areas for waiting passengers and pedestrians)?											

4.2 Are pedestrian facilities free of any obstructions and deterioration?											
4.3 Are entrances and exits for rest and service areas planned at points with good overall visibility?											
4.4 Are there sufficient parking spaces (prevention of safety problems from reduced cross sections and visibility)?											
4.5 Are existing and planted trees a sufficient distance away from the road or out of reach of vehicle users?											
4.6 Is the guardrail correctly installed, regarding: - End treatments: - Anchorages, Rail overlap?											

Field investigation form

Name of road		inspection date
Length(Km.)		coordinates
Weather Condition		
Road Geometry(Alignment, Cross section and Drainage)		
Road surface condition		
Traffic signs, Markings and Lighting		
Road side environment		
Additional comment	Image	

Appendix-2 Sample pairwise comparisons of AHP analysis

Appendix-3 Pictures taken from site

A-3-1Pictures of Kazanchis Road (Development bank-Hanan Bakery-Kazanchis total)

Figure 1.Photo.Water ponding on the walk way & pavement edge, damaged traffic sign & Lighting pole

Figure 2.Photo. Blocked road side drainage, deteriorated walks way and walk way reduced by parked vehicle.

Figure 3.Photo.Signals at the wrong position and are not functional, missing kerb, surface defect of walk way

Figure 4.Photo. Poor visibility of sign and damaged traffic sign, missing kerb, vehicles parked on the walkway

Figure 5.Photo.blocked drains, Insufficient pedestrian and passenger facility, the service area and taxi station very close to each other, worn walk way, insufficient parking space for taxis, road side vendors at night, no road side lighting.

A-3-2 Pictures of Leghar-Stadium-Meskel square

Figure 6.Photo. Faded longitudinal and pedestrian cross markings, unprotected utility line burrow, construction materials on walkway.

Figure 7.Photo.wide taxi bay, good directional and longitudinal road markings, faded longitudinal and cross markings.

Figure 8.Photo. Insufficient passenger facility, good visibility of road marking and lighting, unprotected opened utility line manholes.

A-3-3 Pictures of Welosefer-Ibex-Wengelawit

Figure 9.Photo.Construction material on the walkway, blocked inlet, improper inlet cover

Figure 10.Photo.Construction fence block the walk way and obstruct both pedestrian and vehicle movement, damaged lighting

Figure 11.Photo.Old cross marking is not removed, damaged lighting, blocked inlet

Figure 12.Photo.Uncovered ditch filled by mud and dirt, damaged lighting, branch of vegetation obstruct pedestrian movement.

Figure 13.Photo.Uncovered ditch, Long branch of vegetation, construction material on walk way, incorrect placement of warning sign.

Figure 14.Photo.Damaged traffic sign, blocked ditches.

Figure 15.Photo.Damaged walk way, vehicles parked on walkway, faded pedestrian cross marking and dumped construction material on walkway

Figure 16.Photo.Construction materials dumped on the walkway, blocked ditches

Figure 17.Photo.Uncovered and blocked road side drainage inlets filled with dirt

Figure 18.Photo.Blocked inlets, trashes on walkway

Figure 19.Photo.Uncovered ditch filled with dirt, damaged lighting

Figure 20.Photo.Ponding water on the pavement surface due to poor drainage, steep vertical alignment, construction fence reduce walkway width

A-3-4 Pictures of Filamingo-Olompiya-Shoa supermarket

Figure 21.Photo.Damaged traffic sign, blocked inlets

Figure 22.Photo.Faded road marking, road side vegetation obstruct visibility of traffic sign

Figure 23.Photo.Faded road marking, road side vegetation obstruct visibility of traffic sign

Figure 24.Photo.Invisible road marking at night, no lighting and delineation at the underpass located around dembel

Figure 25.Photo.No road side lighting immediately after Shoa shopping up to welosefer roundabout

Figure 26.Photo.No lighting atWeloseferroundabout

A-3-5 Pictures of keraroad(mexicokera taxi station-bulgariya-kera)

Figure 27.Photo.Excavated material on walkway, blocked road side drain

Figure 28.Photo.Longitudinal and transverse pavement crack

Figure 29.Photo.Pavement crack and blocked roadside drainage inlet

Figure 30.Photo.Deteriorated walk way, blocked inlet

Figure 31.Photo.Deteriorated Island, blocked poor drainage

Figure 32.Photo.Uncovered ditch, ponding of water on the pavement surface, faded pedestrian cross marking, damaged median, obstructed walkway

Figure 33.Photo.Blocked road side inlet, construction debris on walkway, uncovered ditch, and improper drainage cover

Figure 34.Photo.Construction fence and debris reduced walkway width, damaged sign, faded marking

Figure 35.Photo.Incorrect drainage cover, blocked walk way, pedestrian cross marking is not continuous up to full width of the road

Figure 36.Photo.Interrupted pedestrian cross marking, poor drainage

Figure 37.Photo.Poor night time visibility

A-3-6 Pictures of St. joseph School-Global-Agona Cinema

Figure 38.Photo.Damaged walk way, pavement depression, water ponding on the pavement surface

Figure 39.Photo.Trashes and vegetation reduced walk way width, Pavement surface deterioration

Figure 40.Photo.Provision of pedestrian walkway is not continuous on both sides of the road

Figure 41.Photo.Faded pedestrian cross marking, damaged traffic sign, Long Branch of road side trees.

Figure 42.Photo.Traffic sign obstructed by road side trees, deteriorated walk way, old pedestrian cross marking are not removed

Figure 43.Photo.Unremoved pedestrian cross marking, Deteriorated pavement surface, dumped construction material on walkway, excavated material on walk way

Figure 44.Photo.Walkway width reduced by construction fence, roadside debris on the walk way, damaged guard rail and hazardous object in the median, poor drainage and damaged walk way

Figure 45.Photo.Poor night time visibility due to non-functional road side lighting