JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Assessment of the Effects of Road Geometric Design Elements on Traffic Safety:

A Case study from Gohatsion to Dejen Town

A Thesis Submitted to the School of Graduate Studies of
Jimma University in partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering Stream)

By

Lingerew Yizengaw

January, 2017

Jimma, Ethiopia

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Advisors:

Main Advisor: **Prof, Dr.-Ing** Esayas Alemayehu (**PhD**)

Co-Advisor: **Eng.** Tarekegn Kumela (**MSc.**)

January, 2017

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DECLARATION

I, declare that the work which will be presented in this study entitles **"Assessment of the Effects of Road Geometric Design Elements on Traffic Safety (A Case study from Gohatsion to Dejen Town)"** is original work of my own, and It has not been presented for a degree in any other university.

Submitted By:

Lingerew Yizengaw	___________	____/____/____
Student	**Signature**	**Date**

Approved By:

1. Prof, Dr,-Ing Esayas Alemayehu (PhD)	___________	___/_______/____
Advisor	**Signature**	**Date**
2. Eng. Tarekegn Kumela (MSc)	___________	____/______/____
Co-Advisor	**Signature**	**Date**

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ABSTRACT

The rapid and extensive increase in the number of motor vehicles caused certain negative results world-wide. Mitigating traffic accident disaster is of a prime concern and through the analysis of this study attempts are made to correlate road geometric constituents with the rate of traffic accidents. Road geometric design elements and traffic compositions were taken into consideration, and explanations were given on how they affect traffic accident in the region.

The Abay Gorge, along Gohatsion–Dejen alignment, in Ethiopia witnesses frequent Road traffic accident catastrophes each year. As a research objective, this study has evolved to find the correlation between accident rate and road geometric constituents through examining the feasibility of statistical analysis techniques over the indicated variables. Accordingly, nine accident locations having frequent accident occurrences have been identified based on traffic police records obtained from two police stations. Then the accident rates of these subsections were determined. Next, the values of geometric parameters about these sub-sections are obtained from as-built road design outputs. Finally, a regression analysis is made between the selected geometric parameters and accident rates. Exploratory data analyses were conducted using Microsoft Excel Software to investigate relationships and checking of assumptions underlying the use of statistical analysis techniques, specifically using correlations and regression analysis of the data. The correlation is established in the form of an equation of Accident Rate (AR) as a function of road geometric parameters by considering the effect of individual elements on traffic accident. At the end of the study, significant relationships were found between some geometric design elements and accident rates that its impact agrees with the engineering intuition as expressed by the linear relationship between Accident rate and horizontal Radius (AR = 7.3053- 0.7334*R, with R^2 = 0.9395).

Thus, a combination of road geometric constituents correlates better with the rate of traffic accidents than individual geometric characteristics when multiple regression analysis is used with the highest value of coefficient of determination (R^2= 0.952).

Buses/ Mini Buses and Heavy vehicles like trucks are involved in a maximum no of accidents representing 48.51% and 15.18% respectively followed by Pickups (12,21%), Others (6.93%), Cars and Station Wagon (6.27%), and Motor Cycle and Cycle (2.31%).

Injuries are the dominating types of accidents constituting the highest variations in accident's degree of severity (47.1%) followed by PDO (28.9%) and Fatal (24%) crashes.

Key Words: Traffic safety, Road geometry, Accidents, Statistical Methods, Northwest Ethiopia.

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

Description **Page**

LIST OF FIGURES

Description **Page**

ACRONYMS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AR	Accident rate
DF	Degree of Freedom
ERA	Ethiopian Road Authority
ETRADA	Ethiopian Road Accident Data Acquisition
FHWA	Federal Highways Administration
GIS	Geographic Information System
MS	Mean of Squares
MVKm	Million Vehicle Kilometers
NRA	National Road Authority
PDO	Property Damages Only
RSDP	Road Sector Development Program
RTA	Road Traffic Accidents
SPSS	A statistical Package software for Social Science
SS	Sum of Squares
TA	Traffic Accident
TRB	Transportation Research Board
TRL	Transport Research Laboratory
VIF	Variance Inflation factor
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background

It is known that the availability of a road network of an appropriate level of service and quality is vital in expediting the overall economic development of one country. Traffic safety in this regard has a paramount effect on transportation systems of the whole world.

Road crashes are global disasters affecting many lives and livelihoods, hindering development and leaving millions in greater vulnerability [1].

Road traffic accidents are very common all over the world and nearly 1.3 million people die in road crashes each year, on average 3,287 deaths a day with an additional 20-50 million are injured or disabled. It is the leading cause of death among young people ages between 15 to 29, and the second leading cause of death worldwide among young people ages between 5 to 14 years. Unless action is taken, road traffic injuries are predicted to become the fifth leading cause of death by 2030[2].

Now a days, Road traffic accidents (RTAs) constitute major health, economic, and developmental challenges of developing countries, especially adversely affected sub Saharan African Countries [3]. According to the detailed analyses of global accident statistics by the UK Transport Research Laboratory (TRL), the change in road traffic accident fatalities in the low and middle-income countries was found increasing highly.

In assessing the magnitude of the problem of road traffic accidents, according to WHO, 1.2 million people die through road traffic crashes annually. On the average, in the industrialized countries, and also in many developing countries, one out of every ten hospital beds is occupied by a road traffic accident victim [4]. In 2002, for instance, an estimated 1.2 million people were killed in road traffic crashes [5]. 90% of the traffic crashes occurred in low and middle income countries of which Sub-Saharan countries had faced the highest accident rate, which is substantially higher than any continent in the world [6]. From the low-income countries, Ethiopia has been found one of the countries with the highest rate of fatalities per vehicle of accident in the world. According to the Ethiopian Government reports, at least 70 people die in every 10,000 vehicle- accidents per year and the traffic accident death rate per ten thousand motor vehicles in 2001/2- 2004/5 was in the range of 129 and 145 [7].

Road safety engineers have been faced with the challenges of balancing between the type of roads and neighborhood characteristics to address safety issues within the three major traffic safety pillars: human, vehicle, and infrastructure [8].

Although the main concern of this study is the effect of highway geometric characteristics, the road user behavior is also an effective cause of traffic accidents on the design considerations. An error in perception or judgment or a faulty action on the driver's part can easily lead to a crash. However, the number of accidents can be seriously reduced if the road factor is evaluated better and highway design is made correctly [9].

Apparently, most of the developed countries have adopted Road geometry improvement technologies and traffic safety management systems to further enhance and strengthen transportation sector services for the wellbeing of their economic growth [10]. As a result, in these countries the potential improvement and advancement of Road geometric design technologies are becoming virtually unlimited.

But as for the developing countries, especially Ethiopia, there has been a huge gap between the ratio of the underlying transportation service demand to the service available and quality of constructed roads on traffic safety issues [11]. Hence, poor provision of road infrastructure facility needs an immediate remedy as for having faster economic growth and allow safe or free movement of people and goods throughout the country.

Traffic safety problems at adverse geometric design features, and complex disturbances related to visibility obstruction due to fog and smoke, i.e. more likely to occur at night are the common events in many areas along road cuts, hilly and mountainous regions of the highlands of Ethiopia [12]. The Nile Gorge, which is one of the largest canyon in Africa, is part of the central highlands of Ethiopia causing sever road traffic accidents in the region.

Detailed studies on the main trunk road segment from Gohatsion to Dejen will give an opportunity to deal with problems and provide the best remedial measures for the effects of different road geometric parameters independently to minimize loss of life and property damages by defining a methodology to better understand road geometric features that lead to traffic accident through addressing the proposed questions using a Post-accident approach to find correlations between road geometric parameters and traffic accidents integrating with a statistical regression analysis method[13].

Therefore, understanding of the nature and type of road traffic accidents and identifying the contributing effects of road geometric features has a paramount importance to implement remedial solutions for these disastrous problems on the subject area. In light of these, in this research it was tried to assess and avail information on traffic accidents and the effects of geometric characteristics of the Gohatsion–Dejen Road segment, considering the great Nile Gorge section in particular.

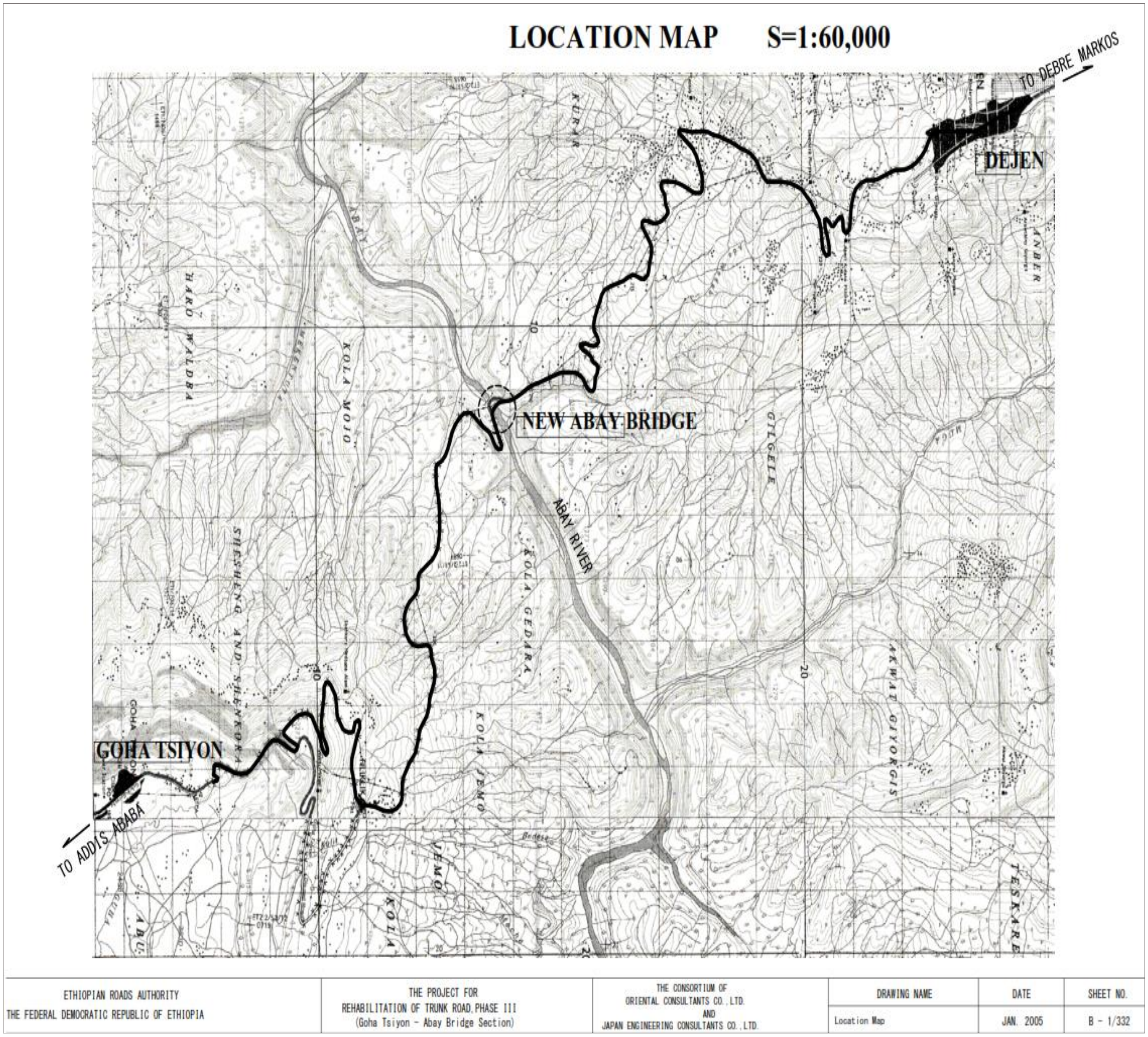


Figure 1.1: Location map of the study area (source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2008).

1.2 Problem Statement

In recent years, road traffic accident in Ethiopia is one of the worst accident records in the world [15]. Many trunk roads have experienced an increase in traffic accidents over considerably visible stretches. However, causes of traffic accidents in Ethiopia are limited only to traffic police officials and are mostly reported as the problem of road users with little consideration of road and road environment factors due to lack of skill and experience about the effect of road constituents on traffic safety.

The Nile Gorge, which is one of the largest canyon in Africa, is part of the central highlands of Ethiopia and is expressed by a very steep or deep topography causing sever road traffic accidents in the region. The geometry, road condition and topography of the main trunk road segment from Gohatsion to Dejen is not suitable for smooth driving.

This study for the present and worst conditions on individual road geometric parameters such as horizontal and vertical alignments leads to the establishment of appropriate Engineering measures that can withstand road traffic accident problems in the study area.

Taking into consideration the fact that traffic safety is a commonly observed problem on the subject road, establishment of correlations between geometric parameters and road traffic safety aspects is vital, in that it can create an understanding on the basic root causes of traffic accidents, and can be imperative for further assessment and quantification of the remedial measures. For this purpose, geometric measurements and investigations of other road external factors like traffic safety features have to be made on a number of locations.

The Gohatsion–Dejen road alignment is subjected to frequent traffic accidents each year due to the different factors including the existence of poor geometrical setup for road construction, insufficient provision of traffic safety features and type or nature of vehicles using the road.

A Thorough understanding on this road segment has an importance and will give an opportunity to deal with problems and deliver the best remedial measures for the effects of different road geometric parameters independently to minimize loss of life and property damages.

Thus, all disappointments of road users using the road segment across the Nile gorge from Gohatsion to Dejon related to the influence of geometric components on traffic safety have to be mitigated.

1.3 Objectives

This research has both the general and specific objectives as depicted below.

1.3.1 General Objective

The general objective of this study is to determine the effects of road geometric design elements on traffic safety in the case of Gohatsion to Dejen road segment.

1.3.2. Specific Objectives

The specific objectives of this study include the following important points.

1. To investigate the influence of traffic and geometric design characteristics on traffic accident.
2. To assess the relationships between traffic accident and road geometric design elements using statistical analysis techniques.
3. To identify the number and types of vehicles involved in a traffic accident at the study area.
4. To propose engineering measures about the influence of traffic and geometric features on accidents.

1.4 Research Questions

The main questions to be answered through the research process include the following points:

1. What are the effects of road traffic and geometric design elements on traffic accident?
2. What is the relationship between traffic accident and geometric design elements?
3. Which types of vehicles are involved in a traffic accident along the study segment?
4. What are the feasible engineering treatments and best practices applied to minimize road related traffic accident problems along the study area?

1.5 Significance of the Study

Drivers and passengers using the road segment across the Nile gorge from Gohatsion to Dejen are being affected due to the influence of road geometric constituents on the whole transportation systems of the region.

Based on the existing models and principles this research addresses the general objectives through investigating the influence of road geometric components on accidents for full and efficient transportation systems of the area. For this intended purpose, geometric and traffic data are collected from the existing as built road design values and traffic accident data is also collected from the worst or frequent road accident locations recorded by traffic police as a data base system. Generally this research significantly comprises the following important points.

- Minimize the possible occurrence of traffic accidents through indicating improper functioning of road geometric features and traffic delineators.
- Answer all the research questions and propose possible solutions or recommended values for the indicated traffic safety problems.
- Used as a source while preparing annual plans in relation to spatial and financial programs for proper design and maintenance of roads and traffic safety regulations of the area.

1.6 Scope of the Study

The scope of this research is limited only to investigate the effect of road geometric features on traffic safety issues through collecting accident and road geometric design data from different institutions. Field measurements at accident locations have been extracted and recorded together with the traffic accident data reported by traffic police officials in order to compare the results with the existing as built road geometric design values.

The most important works being done are outlined in the research methodology section.

Final decision have been reached on which of the chosen parameters (carriageway width, curvature, super elevation, and grade) affect traffic safety systems of the area after applying correlations and regression analysis between the existing design values of road geometric components and traffic accident data recorded as a databases system.

Countermeasures are proposed for the chosen road geometric parameters only.

1.7 Organization of the Research

This study is comprised of five chapters and the contents are outlined below:

Chapter-1 gives a brief description of the thesis background, statement of the problem, research questions and objectives of the thesis work, scope or delineation, significance of the study, structure of the thesis and limitation of the study.

Chapter- 2 presents a comprehensive review of various literatures related to the theme under consideration in order to find critical facts and findings which have already been identified by previous researchers and numerous studies in and around the causes and effects of traffic accidents with particular reference to causes of deaths of road traffic accident casualties.

It covers the most significant parts of the subject area, and is intended to serve as an introductory input to the subsequent analysis stages of the research by seeking to improve the knowledge and experience about road traffic safety and its contributing factors which will guide the direction of this study and aid in exploring the unknowns.

Chapter-3 deals with the description of the methodology followed for conducting different analysis techniques to acquire the causal relationships between road geometric characteristics and traffic safety problems. It gives an Outline of the general steps followed, methodology of study segments, sources of data and data collection used in this work.

Chapter-4 briefly describes the evaluation of results and findings using correlation and regression analysis techniques. Analysis and discussion was carried out, whether the result satisfies the requirements set under the specification of national road safety manuals and remedial measures to be taken on the accident prone sections of road geometric constituents.

Chapter-5 presents the key conclusions derived from the results and findings of this study. Possible recommended values are also suggested as future areas of research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive review of various literatures related to the topic under consideration in order to find critical facts and findings which have already been identified by previous researchers and numerous studies in and around the causes of road traffic accidents with particular reference to the effects of road geometric features on traffic accident. It covers the most significant parts of the subject area, and is intended to serve as an introductory input to the subsequent analysis stages of the research by seeking to improve the knowledge and experience about road traffic safety and its contributing factors which will guide the direction of this study and aid in exploring the unknowns.

It aims to critically assess and identify geometric elements relevant to the traffic safety of roads including geometric requirement of roads such as lane width, nature of curves, super elevation and gradients, length of roadway alignment and approach sight distances through the evaluation of existing mathematical and statistical models for the existence of casualties in road accident using correlations and statistical regression techniques.

A large number of studies have been conducted so far elsewhere in the world to characterize and quantify the relationships between traffic safety and road geometric characteristics. It would be impossible to mention all of them in the space available. However, a summary of the major conclusions regarding the effect of geometric features, drivers, vehicles and other road environment factors on traffic safety will be described in the following sections.

Conscious efforts have also been made to incorporate and utilize the information obtained in the context of the current situation in Ethiopia with particular to the road segment from Gohatsion-Dejen selected for the case study as it will give an opportunity to deal with problems and provide remedial measures for the effects of geometric design constituents on traffic safety.

2.2 Review of Previous Studies

In recent years, engineering bodies have issued to improve road design standards and coincide with information drawn from road safety reports. This includes improving the road geometry and its environment [16].

There have been numerous efforts to investigate the outcome of accidents as related to roadway design features, environmental conditions, drivers' characteristics and traffic features.

Observational studies undertaken in Ethiopia indicate that disobeying traffic control devices is a major problem [13]. This noncompliant behavior of drivers also extends to other causes of accidents like speeding, failure to give priority to pedestrians, and incorrect overtaking. Moreover young drivers in the age category 18-30, particularly in professional driving are riskier in their behavior [17].

Traffic safety is the result of a balance between the type of the road and neighborhood characteristics. The imbalance results in statistically significant differences in concentrations of accidents. Many traffic accidents are the product of several factors such as human error, weather conditions, surrounding vehicle and road conditions [11].

Traffic safety problems at adverse road geometric design features, and complex disturbances related to visibility obstruction due to fog and smoke, i.e. more likely to occur at night without street lighting leads to more severe injuries[18].

Road traffic safety issues are common problems in many areas; along road cuts, hilly and mountainous regions of the highlands of Ethiopia and accident probability usually increases in mountainous and escarpment terrain road sections [19]. The Gohatsion–Dejen road segment is part of the central highlands of Ethiopia having remarkable traffic safety problems due to the existence of poor geometrical setup for road construction.

Detailed studies on this road section can give an opportunity to deal with problems and provide the best remedial measures for the effects of road geometric constituents independently to minimize loss of life and property damages.

Statistical models have been developed to determine a correlation between the chosen road geometric characteristics and traffic accident data using a purpose built statistical modeling programs (regression analysis). It will begin by examining a data set of recorded accident values from police reports and road geometric design data obtained from ERA. However, road geometry external factors to the roads environment such as drivers' behaviors are not included in this study due to time and space available.

2.2.1 Correlation and Regression Analysis

Regression analysis is a statistical technique that is very useful in the field of engineering and science in modeling and investigating relationships between two or more variables [20]. The method of regression analysis is used to develop the line or curve which provides the best fit through a set of data points. This basic approach is applicable in situations ranging from single linear regression to more sophisticated nonlinear multiple regressions. The best fit model could be in the form of linear, parabolic or logarithmic trend. A linear relationship is usually practiced in solving different engineering problems because of its simplicity.

Linear regression analysis is a statistical method for modeling the relationship between two or more variables using simple and multiple linear equations [20].

In this research work, an attempt is made to apply single linear regression models to characterize the influence of road geometric parameters on the rate of traffic accidents using a statistical approach. Simple linear regression refers to a regression on two variables while multiple linear regressions refers to a regression on more than two variables.

A statistical software program (SPSS) has been used in regression analysis to find the effect of road attributes on accident rate.

The general equations of a probabilistic single and multiple linear regression models are presented in the following forms [20].

$$Y = \beta_0 + \beta_1 X + \varepsilon \qquad (2.1)$$

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 \ldots + \alpha_n x_n + \varepsilon \qquad (2.2)$$

Where, the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients α_0, α_1, $\alpha_2 \ldots \alpha_n$ *are* termed as multiple regression coefficients which is not applied in this study. The standard error term (ε) is used to estimate the dispersion of prediction errors when it is needed to predict dependent values from the independent variables in a regression analysis.

The basic assumption to estimate the regression coefficients of the single regression model is based on the least square method. The correlation coefficient R^2 only gives a guide to the "goodness-of-fit" or how closely variables X and Y are related. It does not indicate whether an association between the variables is statistically significant. A number of techniques can be used to judge the adequacy of a regression model, some of which are standard error (ε), R-squared value (R^2), R-adjusted and the p-value. The value of R^2 is always between 0 and 1, because R is between -1 and +1, whereby a negative value of R indicates inversely relationship and positive value implies direct relationship. Confidence of the result indicates in terms of significant value (P). The correlation was considered significant if (P) is zero or 5 % different from zero [21].

2.3 Possible Causes for High Number of Road Traffic Accidents

The reasons for the relatively high number of road traffic accidents includes the following [22].

- Lack of driving skills
- Poor knowledge of traffic rules and regulations
- Violation of speed Limit
- Insufficient enforcement
- Lack of vehicle maintenance
- Animal drawn carts and animals frequently using in main highways
- Lack of safety conscious design and planning of road network
- Disrespect of traffic rules and regulations
- Lack of general safety awareness by pedestrians and
- Lack of medical facility in general, which increase the severity of accidents.

A review of the major assessments regarding the effect of road environment, drivers, and vehicle factors on traffic safety will be discussed in the following sub sections.

2.3.1 Road Environment

Road environment has impacts on occurrences of road traffic accidents. In developed countries, there have been continuous efforts to meet the safety standards of roads through safety audit during the planning, designing, and operation stages. In Africa road network is expanding fast, maintenance standards have started improving lately, and there is potential for improving the safety standards of the roads [23]. In Ethiopia, the police have limited road and traffic engineering skill in general and thus they underestimate the contribution of roads and road environments to traffic accidents and especially they lack trainings on the subject areas [24].

2.3.1.1 Road Geometric Design Elements Affecting Traffic Accidents

At the end of a study in which more than 400 research data obtained in the past are evaluated, it was found that there are over 50 highway design elements for different highway classes and these elements are related with traffic accidents in one way or the other.

A design elements' classification with units, used in a study evaluating the effects of safety in highway projects are given as below [25].

Roadway

- Number of Lanes (Lane)
- Lane Width (Foot/m)
- Surface Condition (Good/Bad)

Vertical Alignment

- Grade on Tangent (%)
- Grade on Curve (%)
- Sight Distance (Feet/m)

Horizontal Alignment

- Degree on Curve (Degree)

Shoulder

- Width (Foot/m)
- Surface Condition (Good/Bad)

Traffic Control

- Delineator (Yes or No)
- Guide Sign (Yes or No)
- Lighting (Yes or No)
- Marking (Yes or No)

Median Width (Foot/m)

i. Horizontal alignments

The horizontal alignment of a road may comprise straight lines, circular curves (with a constant radius), and spiral curves, whose radius changes regularly to allow for a gradual transfer between adjacent road segments with different curve radii. Inconsistent horizontal alignments of roads with sharp curves are known for their substantial and adverse safety impacts [24].

Several studies have shown that traffic accident in curves is so much high.

- The accident rate in curves is 1.5 to 4 times higher than in tangents [26].
- From 25% to 30% of fatal accidents occur in curves. Approximately 60% of all accidents to occur in horizontal curves are single-vehicle off-road accidents. [27].
- The proportion of accidents on wet surfaces is high in horizontal curves.
- Accidents occur primarily at both ends of curves. 62% of fatalities and 49% of other accidents occurring in curves, the first maneuver that led to the accident was made at the beginning or the end of the curve [19].

Thus, there is a relative relationship between the speed reduction in the curve and the probability of accident: When the required speed reduction in the curve is high, the probability of error and accident becomes also so high (encroachment, skidding, run-off- the road, etc.). Moreover, the risk is even higher when the speed reduction is unexpected or unusual (isolated sharp curve [28].

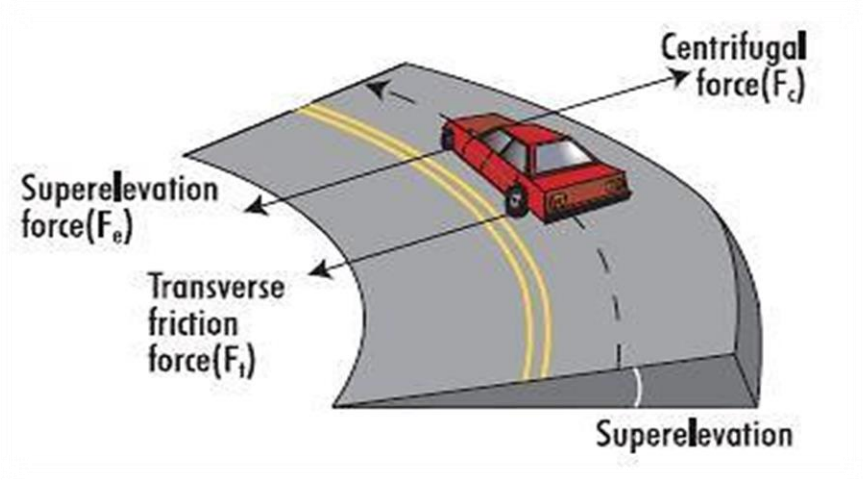


Figure 2.1: Curve-System of Forces [28]

An important factor, which affects the occurrence of road traffic accidents in terms of frequency and severity, is the road alignment.

Recent studies show that accidents on horizontal curves are causes for concern in all countries.

It has been shown in past researches that horizontal curves experience crash rates of up to 4 times the rates on tangent sections, all else being equal [29].

The following traffic, roadway, and geometric features that influence safety at horizontal curve sections have been identified [30]:

- Traffic volume on the curve and traffic mix (such as the percentage of trucks)
- Curve features (such as degree of curve, curve length, super elevation, presence of transition curves)
- Cross sectional curve elements (such as lane-width, shoulder width, shoulder type, shoulder slope)
- Curve section roadside hazard features (such as clear slope, rigidity, and types of obstacles)
- Stopping sight distance on curve (or at curve approach)
- Vertical alignment on horizontal curve
- Distance to adjacent curves

- Distance of curve to nearest intersection, driveway, etc.
- Pavement friction
- Presence and type of traffic control devices (signs and delineation).

It has been indicated that for horizontal curves, casualty crashes seem to be more dominant than PDO crashes. Hazardous roadside designs are the primary cause of crashes at horizontal curve sections. The effect of degree of curvature, tangent length, and sight distance on accident rates at horizontal curve sections was significantly influenced by the degree of curvature [31].

The relationship between accident rate and horizontal curvature was suggested for the main that the critical radius, i.e. the radius below which accident risk increases sharply, is approximately 400m as shown in the figure below [32].

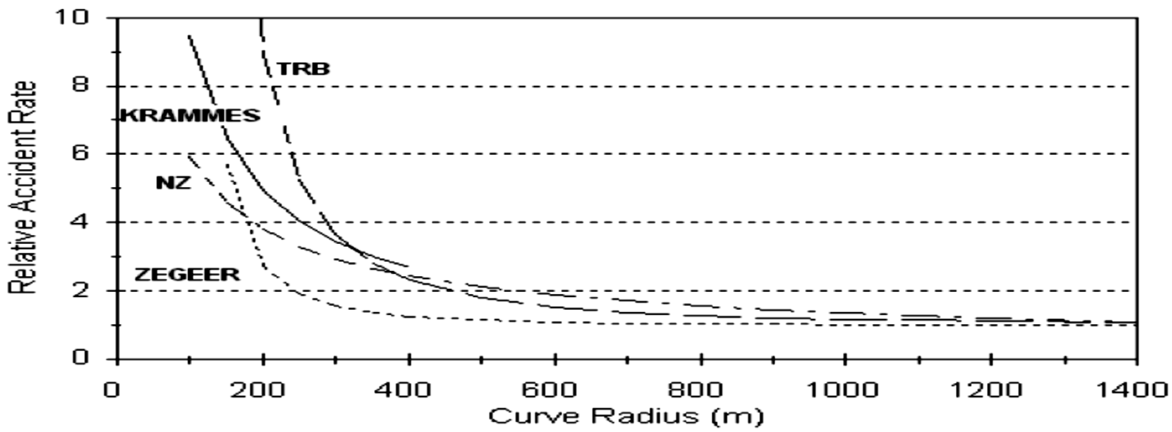


Figure 2.2 the relationship between accident risk and horizontal radius of curvature R [32].

A horizontal curve with R > 1300m can be regarded as the standard against which other curves can be assessed, and is therefore afforded a 'relative risk ratio' of 1.0. In all studies of horizontal curves, it is apparent that an improved understanding of the safety risk associated with horizontal curves can be found by considering the nature of the tangent prior to the curve [32].

Accidents on bends are major problems in many developing countries, although the proportion of such accidents is dependent on both topography and demography of each country.

sharp curves result in much higher crash rates than more gentle curves; sections with curvature of between 5 and 10 degrees have at least twice the crash rate of sections with curvature of 1 and 5 degrees, and sections with curvature of between 10 and 15 degrees have crash rates four times as great. In terms of curve radius, 200 m seems to be the point below which crash rate greatly increases. The evidence suggests that curve flattening is highly effective in reducing crashes [33].

There are several elements of horizontal alignments which are associated with horizontal curve safety [34]. It states that safety of a horizontal curve, its accident frequency and severity is determined by:

Internal features:

- Radius or degree of curve
- Super elevation, etc.

External features:

- Density of curves upstream
- Length of the connecting tangent sections
- Sight distance, etc. that influence driver expectation and curve approach speed.

Road geometric improvements or remedial measures used to ensure safety at deficient horizontal curves include the following points:

- Lengthening the radius of a curve to reduce accidents in sharp horizontal curves.
- Improving warning and guidance provided for drivers:
- Better sight distance, curve conspicuity,
- Signing and marking, delineation.
- Minor geometric improvements, modifications to the shoulder and roadside conditions
- Curve straightening
- Roadway widening at curve sections
- Super elevation improvements

ii. Vertical alignment

There are three main effects of vertical road alignments, which are closely associated with the occurrences of traffic accidents. These are excessive speeds and out-of-control vehicles on down grades, differential speed between vehicles created on both down and upgrades, and low range of visibility that often occurs in the immediate vicinity of steep grades at the crest of vertical curves.

a. Vertical curve

Poor condition of the horizontal and vertical alignments of a road can result in visual effects, which contribute to accidents and are detrimental to the appearance of the road. It may be difficult for a driver to appreciate the sight distance available on crust curve and he/she may overtake when it is insufficient for him to do so safely [35]. Effects of vertical curve have been summarized in such a way that steep grades have higher accident rates than mild ones and grades of less than 6 percent have little effect, but grades steeper than this are associated with higher accident rates [24].

b. Grade

The above researchers indicate that downgrades have greater problems, particularly for truck safety than upgrades. A combination of horizontal curves under 450m and grades over 4 per cent are not recommended.

Steeper grades increase the accident rate, and the accident rate in mountainous terrain is higher than in flat terrain and the effects of vertical road alignment on accident are excessive speed, differential speed between vehicles and visibility difficulty for diver on crest curve[36].

Accident rate is highly increasing with increasing of road grades at the point of high slope section. For the low radius horizontal curves, the accident number is high. Steeper grades above 6 per cent are generally associated with higher accident rates [10].

Accident rate on downgrade is slightly higher than on upgrades, and upgrades have less effect on accident rate while accident rate increases with increasing downgrade.

The main problem in downhill grades is related to heavy vehicles due that the fact that at such locations, the main elements that need to be considered are the increase in stopping distances and the possibility of overheating [37].

iii. Super elevation

Super elevation of a curve is another factor critical to the curve's proper functioning. It is the rotation of the pavement on the approach to and through a horizontal radius and is made to assist the driver by counteracting the lateral acceleration produced by moving across the curve [38].

A number of studies have attempted to link super elevation to accident causation. The available super elevation at fatal accident sites was typically deficient. Curves with too little super elevation had worse accident rates than curves with proper super elevation. Thus, curves with super elevation bellow the **AASHTO** guideline, as specified in a policy on geometric design of highway and streets have significantly worse accident rates than those with super elevation above the minimum guideline [39]. Super elevation values ranging from 5% to 8% are recommended in design and improving the super elevation reduces the number of accidents by 5 to 10% [26].

The adopted criteria allow for the use of maximum super elevation rates from a range of 0.04 to 0.12. Maximum super elevation rates for design are established by policy for each State.

Selection of a maximum super elevation rate is based on several variables, such as terrain, weather, highway location (urban vs. rural), and frequency of very slow-moving vehicles. E.g. northern States that experience ice and snow conditions may establish maximums for super elevation than States that do not experience these conditions. Use of lower maximum value of super elevation rates by policy is made to address the perceived problem created by vehicles sliding transversely when traveling at very low speeds when weather conditions are poor [38].

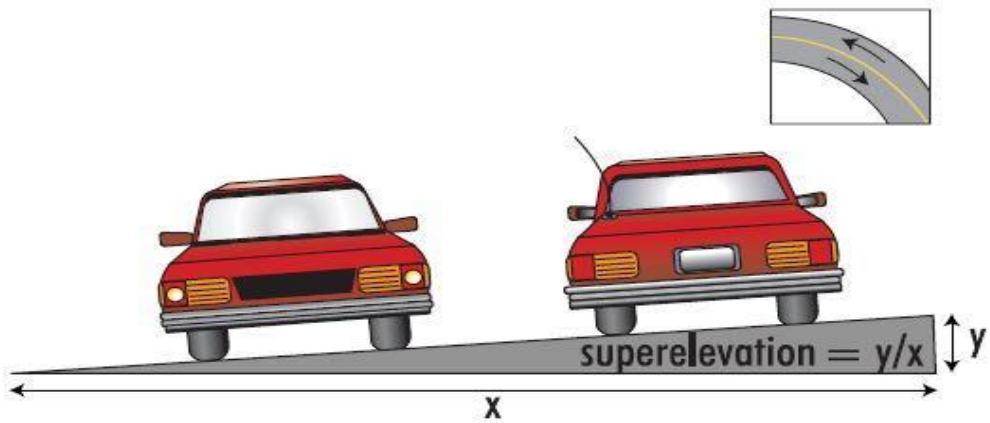


Figure 2.3: Super elevation in Curves [38].

iv. Sight Distance

This is the ability to see ahead in order to stop safely or overtake a vehicle or view approach intersection. Sight obstructions on the road, generally occur due to the presence of deep cuts, embankments, vegetation, walls etc. on the inside of the horizontal curves and intersection quadrants, and sharp crest vertical curves themselves [40]. Types of sight distances are: stopping sight distance, passing sight distance, intersection sight distance, and decision sight distance.

Inadequate sight distance may be a factor in 20 to 25 per cent of accidents resulting from overtaking maneuvers. The actual percentage of crashes in which sight distance has a role would clearly be related to the extent of overtaking maneuvers, which is related to traffic flow [33].

2.3.1.2. Road Cross-Sectional Elements

Various studies revealed that road cross sectional elements are the most important road related features which affect road safety. Road cross-sectional elements comprises lane and shoulder width, side slope, back slope, and clear zone.

i. Lane and Shoulder Width

The typical elements of the cross-section of a two-lane road are provided in the figure below.

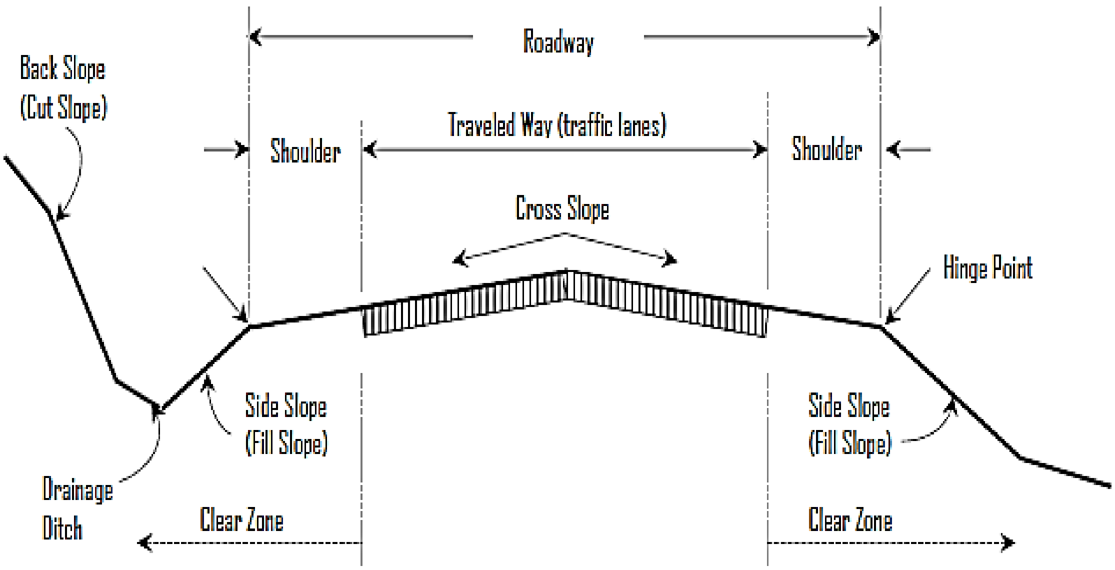


Figure 2.4: Roadway Cross Sectional Elements [29].

Lane and shoulder width affects run off the road and opposite direction accidents. The rate of these accidents decrease with both increasing lane and shoulder width, but the marginal effect of increasing width on accident rates decrease as either the base lane width or the base shoulder width increases. Lane width of 3.4 to 3.7 meters has the lowest accident rate and represents the balance between safety and traffic flow For 3.0 meters lane a shoulder of 1.5 meters or greater, and for 3.3 to 3.6 meters lanes shoulders of 0.9 or greater reduces the accident rate significantly [24]. Widening narrow lanes bring safety benefits up to a width of 3.7 meters, with little benefit beyond that unless the road carries large volumes of trucks [33].

In horizontal curves, the radius followed by a vehicle's front wheels is larger than the radius of its rear wheels, which increases the width swept (as compared to the situation in a tangent).

The additional width is negligible in the case of passenger's vehicles but can be significant with long articulated vehicles. Moreover, the difficulty stemming from changes in direction in a curve increases the risk of encroachment outside the traffic lane [29].

Many literature review findings revealed that road width often needs to be increased in horizontal curves. The required width depends on the curve radius, operation speed and vehicle's characteristics.

Generally, lane width has greater effect on accident rates than shoulder width and increasing road width reduces accident rates as shown in the fig below.

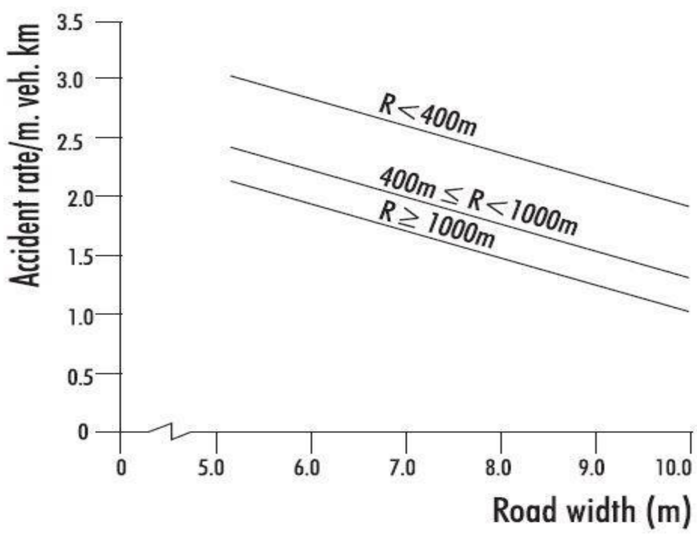


Figure 2.5: Accident rate in curve and road width (Source: Krebs and Kloeckner (1977))

ii. Road side features and side slopes

Roadside encroachments begin when the vehicle accidentally leaves the travel lanes, deviating towards the roadside.

Past researches on the safety of the roadside environment has produced important improvements to roadside features including the development of barriers that better contain and more safety redirect errant vehicles, sign and luminaries supports that break away on impact, causing little damage to the striking vehicle and its occupants. Entry of an errant vehicle on to the roadside border does not in itself mean that an accident is inevitable. Although some dangers always exist, the chances of recovery are excellent if the border is reasonably smooth, flat, and clear of fixed objects and other non-traversable hazards [41].

Measurements to be taken includes the following:

- Proper design and construction of drainage structures such as culverts and headwalls
- Construct Roadside barriers to redirect errant vehicles
- Provide sign and luminaries supports that break away on impact
- Provide clear recovery areas.

Roadside is the area between the shoulder and the right of way limit. The definition of a safe roadside is one which is traversable throughout its length and contains no fixed objects hazards, or, if significant hazards exist, shielding is used to prevent a collision with the hazardous features. Thus, a good design practice should be implemented to eliminate all hazards rather than building hazards from the edge of the road [42].

Treatments provided by AASHTO Roadside design guide for roadside hazards includes:

- Remove the obstacle or redesign
- Relocate the obstacle
- Reduce impact severity by using an appropriate breakaway device
- Redirect a vehicle by shielding the obstacle with a longitudinal traffic barrier
- Delineate the obstacle etc.

2.3.1.3 Speed

Operating speed is influenced by several factors related to the driver, road and road side conditions, vehicle characteristics, traffic conditions and weather conditions [27].

Road alignment is undoubtedly the most important factor among road characteristics that influence driver's speed. A speed variation along a road is a major factor in accident causation which reduces driver's ability to control the vehicle, negotiate curves or maneuver around obstacles on the roadway. This therefore increases the chance of running off the road or into an oncoming vehicle [43].

Speed has the greatest effect on traffic safety and the accident rate decreases as design speed increases from 60 to 80 km/h.

German researchers developed rules to help designers choose horizontal alignment sequences that would reduce operating speed variations along a route [27].

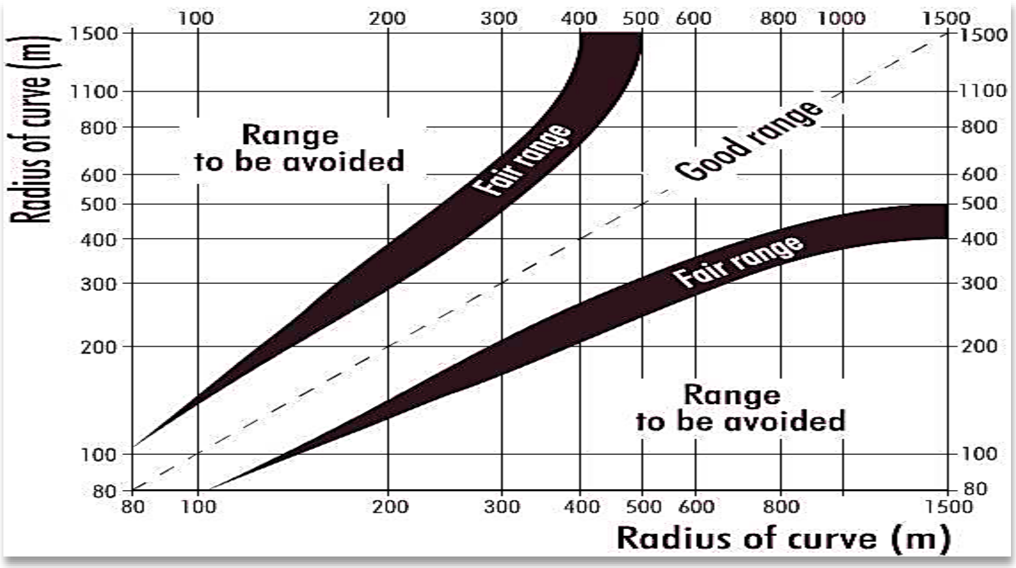


Figure 2.6: Tuning Radii in Cure Sequences [27]

2.4. Traffic Volume and Vehicle Classification

Many literatures indicate that traffic volume is positively correlated with incidences of traffic accidents. As the number of vehicles increases through a section, the exposure to potential accidents and number of conflicts increases [44]. Traffic volumes are considered during horizontal curve widening.

Vehicle classification is also an essential aspect of traffic volume evaluation. The types of vehicles are defined according to the breakdown adopted by **ERA** for traffic counts: cars; pick-ups and 4-wheel drive vehicles such as Land Rovers and Land Cruisers; small buses; medium and large size buses; small trucks; medium trucks; heavy trucks; and trucks and trailers. This breakdown is further simplified, for reporting purposes, and expressed in the five classes of vehicles (with vehicle codes 1 to 5) listed in Table 2-2.below.

Table 2.1: Vehicle Classification by class

Vehicle Code	Type of Vehicle	Description
1	Small Car	Passenger cars, minibuses (up to 24-passenger seats),Taxis, Pick-ups, and Land Cruisers, Land Rovers, etc.
2	Bus	Medium and large size Buses above 24 passenger seats
3	Medium Truck	Small and medium sized trucks including tankers up to 7 tons load
4	Heavy Truck	Trucks above 7 tons load
5	Articulated Truck	Trucks llllk or semi-trailer and Tanker trailers

(Source: Road Asset Management and Contract Implementation Coordination Directorate)

ERA has also classified vehicles into eight categories based on their size (four passenger and four fright vehicles) Table1- 1 shows the detail vehicle classification.

Table 2.2: Vehicle Classification by size

Classification	Descriptiop
A. Passenger Vehicles	
Car	Cars & Taxis
L/Rover	Land Rovers, Jeeps, Stations Wagons, Land Cruisers etc.
S/Bus	Small Buses up to 27-passenger seats
L/Bus	Large Buses over 27-passenger seats
B. Freight Vehicles	
S/Truck	Small and Light Trucks of 3.5 tons load
M/Truck	Medium sized trucks of 3.6 to 7.5 tons load
H/Truck	Trucks and Tankers of 7.6 to 12 tons load
Truck - Trailer	Truck Trailers and Tanker Trailers above 12 tons load

(Source: Road Asset Management and Contract Implementation Coordination Directorate)

2.5. Driver Characteristics

The driver's behavioral characteristics, such as inattention, fatigue, inexperience, and risk-taking behavior (speeding, drunk-driving, and failure to wear a seat-belt), have all been identified as factors that significantly contribute to increased crash and injury risk on roads. The driver's age also plays an important role in crash causation. The key components involved in run-off crashes is the driver's ability to control both speed and direction [45]. It occurs when a driver is faced with a piece of unexpected or unusual information, which leads him or her to over-correct at a large steering angle and the causes of this include:

- Distractions such as talking, eating, etc.
- Aggressive and conservative in nature
- Physical problems like colorblindness, night blindness, drugs or medication
- Drowsiness, fatigued, illness, or blackout
- Speeding; and failure to obey signs, signals or traffic officers.

However, this study tried to address problems associated with road geometric factors.

2.6. Vehicle Characteristics

Mechanical problems in vehicles are another important factor that contributes to traffic accidents. Faulty brakes, worn tires and other vehicle defects affect the controlling of a vehicle, especially at high speeds [45]. It has been observed that at high speeds the tires may blow out leading to loss of control. Vehicle and roadway interactions, such as skid resistance, play a major role in stopping the vehicle from encroaching the off-road features, like the shoulder, median and other traffic signage [46].

There are problems associated with heavy vehicles on rural roads. First, there is the problem of the mix of vehicles on rural roads, and the risk of injury to vehicle occupants involved in a crash with a heavy vehicle. Secondly, there is the problem of single-vehicle crashes involving heavy vehicles, and the contribution of road features to these crashes. Although crashes involving trucks are less common than those involving smaller vehicles, they tend to be more severe than those involving smaller vehicles [47].

Problems related to heavy vehicles on rural roads result from three characteristics [43]:

- Are much heavier and larger in dimension compared with passenger cars, and therefore experience instability and maneuverability problems;

- Have less effective acceleration capabilities than passenger cars and have greater difficulty maintaining speeds on upgrades, and this speed variation generates more instances of overtaking and the potential for head-on collisions with oncoming vehicles; and
- Have a lower deceleration in response to braking than passenger cars, which increases the potential for severe rear-end crashes.

2.7 Traffic Accident Recording Systems in Ethiopia

Regional departments of the Traffic Police are responsible for the recording of all traffic accidents under their jurisdictions. The Federal Police Commission is responsible for national accident data compilation and processing. In each Region's Woreda Police Station, accident data are reported manually. The traffic police accident data form contains accident classification, date, time, day of the week, year, age of the driver, sex, education of the driver, ownership of the vehicle, service year of the vehicle, defects of the vehicle, location of accident, road traffic condition, road surface condition, road junction type, weather and illumination condition, collision type, and property damage and parties injured (age, sex, physical fitness and the like) etc.

Monthly reports are submitted to pertinent the Regional Police Commissions. A yearly report from the Regional Police Commission will then be submitted to the Federal Police Commission to generate national accident statistics. In Ethiopia, much of the information is needed for the traffic police's own activity, primarily, to enforce the law and carry out prosecutions. Some of the accident data are of no direct interest or use to the police, but are vital to the work of other organizations.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter deals with the description of the methodology followed for conducting different analysis techniques to acquire the causal relationships between road geometric factors and traffic accident problems. It comprises an outline of the general steps followed, methodology of study segments, sources of data and data collection used in this work.

The research was achieved by a combination of literature review, and analysis of road geometric and traffic accident data obtained from ERA and traffic police reports respectively.

Many traffic accidents are the product of several factors such as human error, surrounding weather conditions, vehicle characteristics and road conditions [48]. However, this study concentrates mainly on the rate of traffic accidents occurring at geometric elements of the road. Road geometry external factors to the roads environment such as drivers' behaviors were note explored in this study due to time, space and availability of data to cover all problems.

Relationships were developed to bind road geometric characteristics to accident data in order to determine a correlation between radius of curve, carriageway width, super elevation, grade, traffic composition and accident frequency (or, rate of traffic accidents).

Single and Multiple regression analysis models are used to analyze the dynamics of changes, variations and interruptions in road traffic accidents and road geometric characteristics of the subject trunk-road segment selected for the case-study from Gohatsion-Dejen Town using time-series data.

3.2. Location of the Study Area

3.2.1 Location and Accessibility

The study was conducted on the already existed trunk road that has been completed and substantially constructed during the different road sector development phases of the country which had a well-recorded history of remarkable traffic safety problems at an adverse geometric locations particularly from Gohatsion-Dejen section.

It is a part of economically important main Addis Ababa–Debre Markos–Bahir Dar–Gondar–Metema–Sudan root that connects north central and north western parts of the country with the capital of Addis Ababa and port of Sudan.

It is located between Oromia and Amhara National Regional States of North Shewa (Fiichee) and East Gojjam zones at a distance of about 160 Km from Addis Ababa and is bounded between longitude 38º 10’37’’ East, Latitude 10º 04′08″ North and elevation of 3755ft (Google Earth, 2016). The Road connects Gohatsion and Dejen Towns passing through different kebeles and villages having ample raw material resources for lime and cement production, and intensive cultivation of agricultural products, particularly Magna Teff and cereals. The local geology contains sandstone (270m thick), siltstone, clay stone (150m thick), gypsum (150-250m thick), limestone (400m thick), and basalt[49].

It is also the main road that provides a key link to the Ethiopian Renaissance Dam Site for transportation of heavy machineries, equipment and construction materials.

3.2.2 Study Location and Topography

The study area is part of the central Ethiopian highlands and it is characterized by 1400m-1500m deep gorge regionally and rugged topography with an elevation value of around 1700-1900m a.s.l [49]. The present regional physiographical setting of the study area is a result of various processes. Besides, the uplifting which is believed to be responsible for the formation of the deep valley, erosional leveling, weathering and mass wasting have played a major role in creating the present landform including plateaus, steep slopes, and deeply incised valleys and gorges [49].

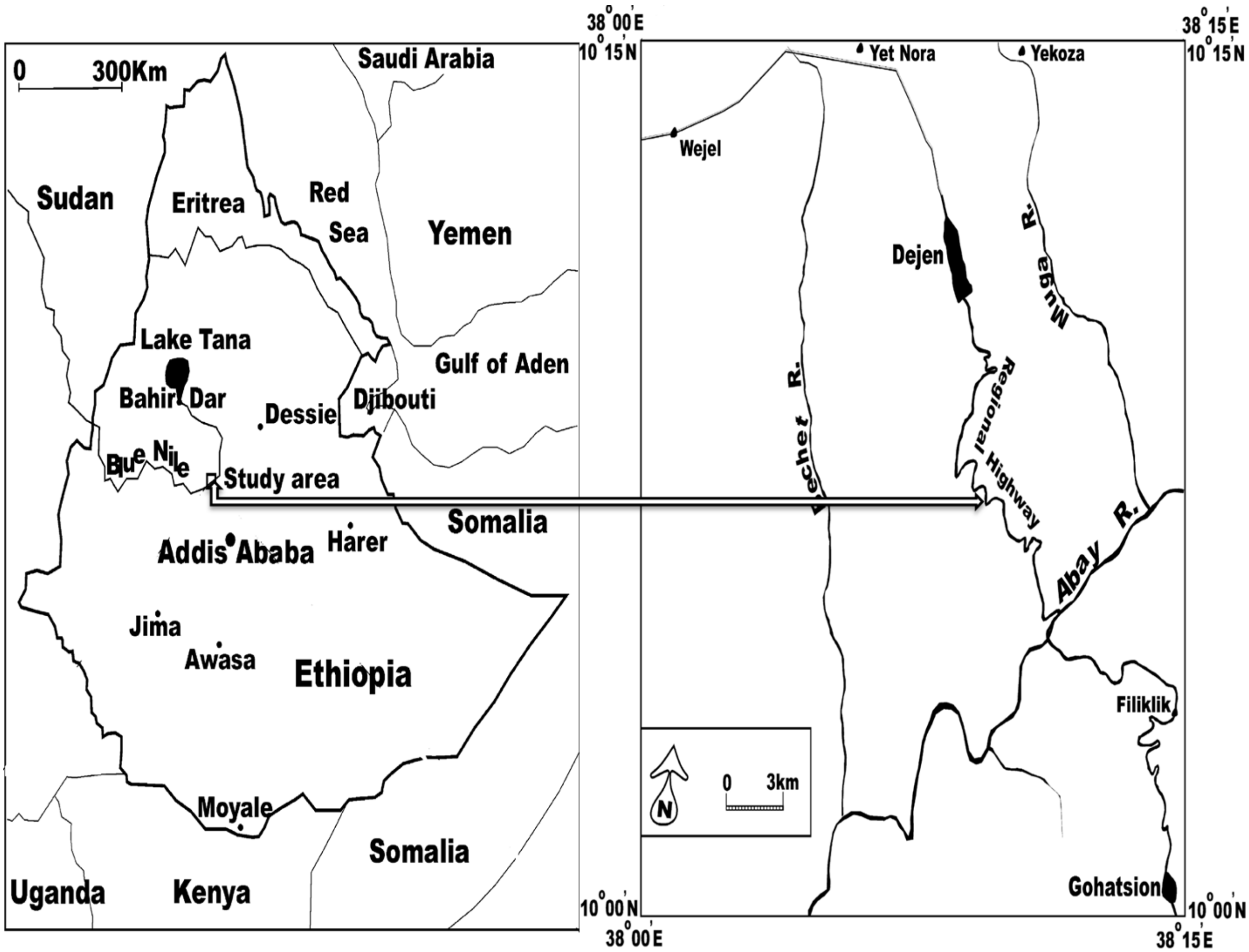


Figure 3.1: Regional setting of the study area (source: L. Ayalew, H. Yamagishi (2004))

3.2.3 Climatic Condition of the Study Area

The Climatic condition of the study area falls under warm subtropical climate condition. The area receives heavy precipitation from June to September and light to moderate precipitation from mid-February to mid-March. The rainfall peaks in July or August at about 300 to 400 mm per month. Existing rainfall observation records in the Abay Gorge area are of 49 years data for Dejen and 34 years data for Filiklik (Gohatsion sub-sheet).

3.3. Study Procedure

The research was achieved by a combination of literature review, and analysis of road geometric and traffic accident data obtained from ERA and police commission offices.

The procedure utilized throughout the conduct of this research study are as follows:

- Review of related literatures including articles, books, and research papers, standard specifications (ERA and AASHTO) etc.
- Conducting visual site visit to get more information and impact about the road structure and its environment.
- Collection of traffic and geometric data of the subject trunk-road selected for the case-study
- Conducting roadway width and related field measurements.
- Obtaining geometric design values from as built- road at selected accident prone sections
- Collection of accident data from traffic police reports of Gohatsion and Dejen stations.
- Conducting statistical correlation and regression analysis between the various road geometric components and accident rates.
- Conducting inferential analysis and subsequently interpretation of results.
- Comparing the results with preexisting literatures, standard specifications and manuals.
- Drawing conclusions and recommendations based on the results and findings inferred during the whole analysis and discussion parts.
- Put appropriate remedial measures to be taken on the indicated problems.

3. 4 Study Period:

This research was carried out from July 2016 to May 20017.

3.5 Data Collection Techniques

Since Non-probability sampling represents a group of sampling techniques and has free distribution that help researchers to select a unit sample from a population, purposive sampling method was adopted for this study. For evaluation of the effects of road geometric parameters, a six year accident data was collected from police commission reports together with geometric and traffic data obtained from Debre Markos and Alemgena ERA district offices.

3.6 Study Design

The existing geometric design and traffic accident data have been used to find statistical correlations between road geometric characteristics and accident rates. The road data is from the Ethiopian Road Authority (ERA) while accidents were collected from traffic police commission offices recorded in a database system. After choosing an area and a period of investigation the analysis method was designed in four phases:

- Collecting accident data (from ETRADA Databases),
- Collecting road geometric design data (from ERA as built road design values),
- Identifying accident locations and combining them with the road geometric design data,
- Analyzing data statistically and conducting inferential analysis and interpretation of results.
- Conclusion and Recommendations have also been stated with Possible suggested values as future areas of work.

For evaluation of the effects of the road geometric parameters, statistical regression technique was adopted, for the results to be considered significant.

For every reported accident data the following information have been recorded in the ETRADA (Ethiopian Road Accident Data Acquisition) databases: accident ID, date, type, place and description, number of killed, severe and light injuries, weekday, time, road condition (wet, dry or snow), lighting conditions etc.

To take advantage of the databases for traffic safety purposes, geometric measurements at accident locations have been extracted and recorded together with the traffic accidents for further analysis.

The flow chart below depicts a summary of the overall evaluation and methods used throughout the research process.

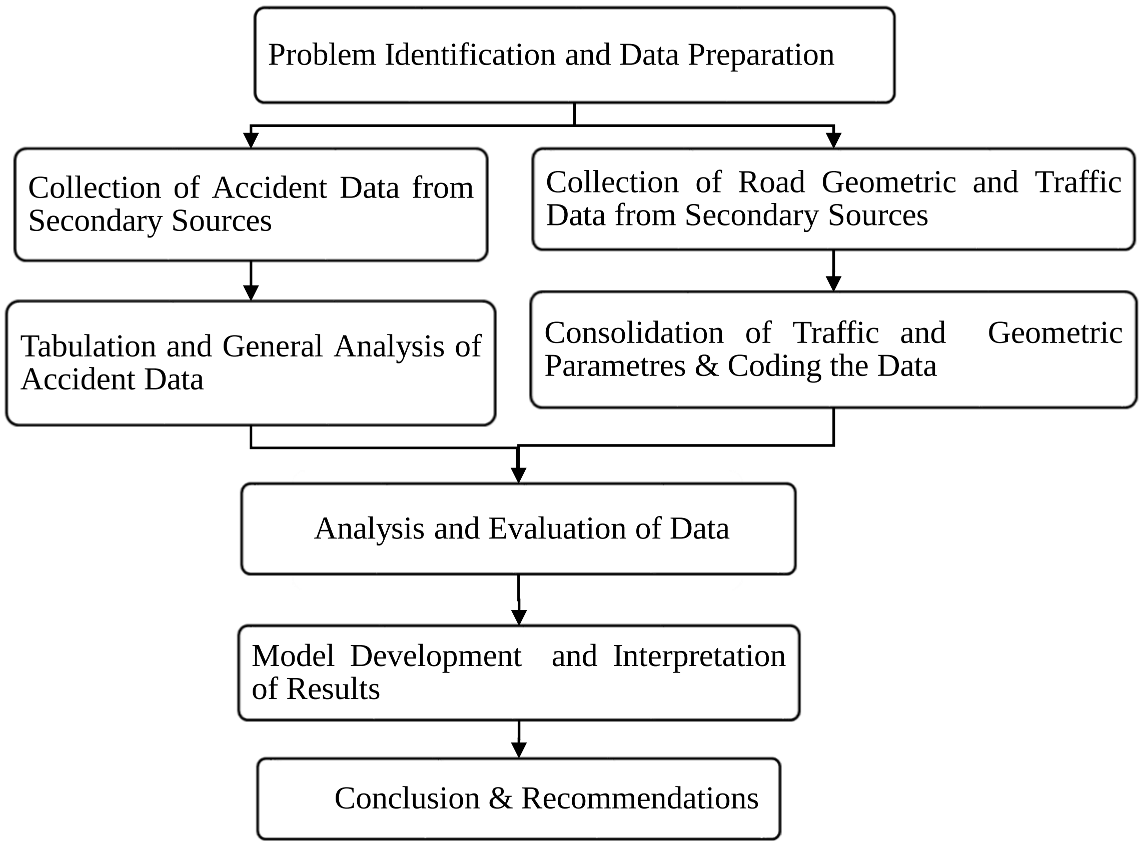


Figure 3.2: flow chart for study methodology**.**

3.7 Study Variables: There are two types of variables that are taken into consideration:

3.7.1 Independent Variables: Traffic and Road Geometric Design Elements.
3.7.2 **Dependent Variables**: Road Traffic Accidents.

3.8 Data Collection Methods: Secondary data was collected through reviewing the existing relevant documents, reports, literatures whereas primary research data was collected through site visits, and direct measurements of geometric components at accident locations.

3.9 Data Types and Sources:

Quantitative as well as qualitative data types have been employed. The data needed for this work was collected from both primary and secondary sources.

It specifically comprised of yearly road traffic accidents and corresponding as-built road geometric design values for the path from Gohatsion-Dejen covering the periods from 2002 to 2007. For the collection of these primary data, this research made use of tape meter and digital camera.

The data was collected as soft copies, hard copies and maps. Additional data was also used for the verification of the collected primary data sources from Google earth through internet and some were modified and presented in the form of tables and figures for practical analysis purpose

3.9.1 Geometric Data

Turning movements on sharp curve areas are also known to generate overturning, out of control and maneuvering problems at the road surface, which can lead to severe crashes and property damages. The selection of specific sections of the road to be evaluated was desired to ensure consistency in this regard. To this effect, as shown in table 3.1 below most of the sections selected for evaluation are on curves (radius varying from 20m to 600m).

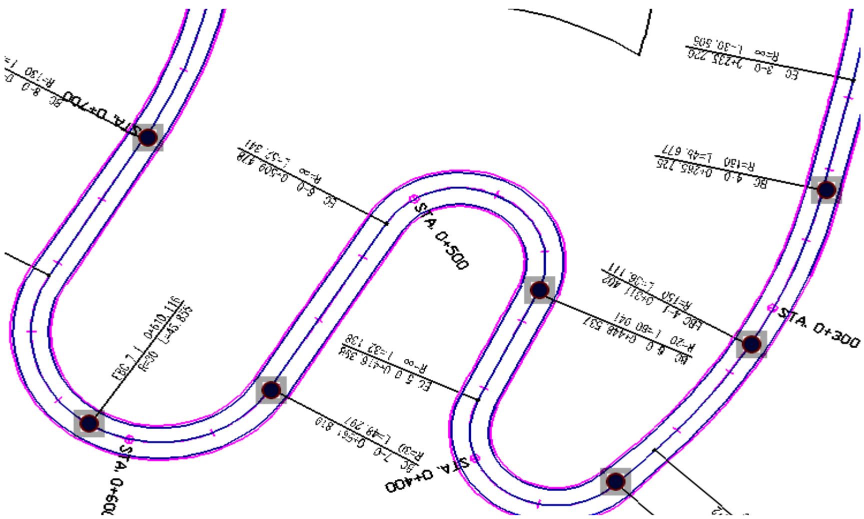


Figure 3.3 Dangerous Geometrical setup at No. five Road Section with Sharp horizontal curves [52].

Out of the various locations, nine sections having frequent accident occurrences were selected from traffic police records with their respective as-built geometric design values, as shown in table 3.1 below.

The following geometric components were collected from the given as-built road alignment design values at locations where traffic police has already ranked as dangerous sub- sections using Auto cad and Arc GIS 10 software.

Table 3.1: Details of As-built Road geometric Design outputs and reported accident data at selected locations.

Sampling Location	Station	Coordinates		Curve Radius (m)	Carriageway Width (m)	Super elevation (%)		Gradient (%)		Traffic Accident
		X	Y			Min	Max	Min	Max	
At No five Road section	0+525	417032.938	1107901.141	20	12.5	3.8	11.8	11.0	8.7	4
Washa Mk. Church	5+00	417112.445	1108298.133	15	8.0	2.5	8.0	9.3	11.7	5
Snt.Gibrile church	26+970	408311.833	1117182.356	50	10.9	5.5	6.9	8.5	11.1	6
Endedir	31+970	407752.207	1119326.403	70	10.9	2.5	2.5	5.3	10.4	3
Bora Afaf	33+970	408888.202	1120540.366	30	9.0	2.5	8.0	4.0	9.6	3
Dembeza Snt. Mary church	35+100	408294.965	1120799.549	42	8.0	2.5	7.5	8.8	12.0	4
MerYesus Church	36+100	408027.777	1121010.326	180	10.6	2.5	7.5	5.2	9.1	2
Gelgele K. Mihiret Church	38+100	407065.022	1122601.664	180	10.6	2.5	3.4	3.5	7.1	4
Gypsom Quary site	39+600	406718.741	1123998.456	600	12.0	2.5	2.5	0.45	3.3	4

(Source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2009).

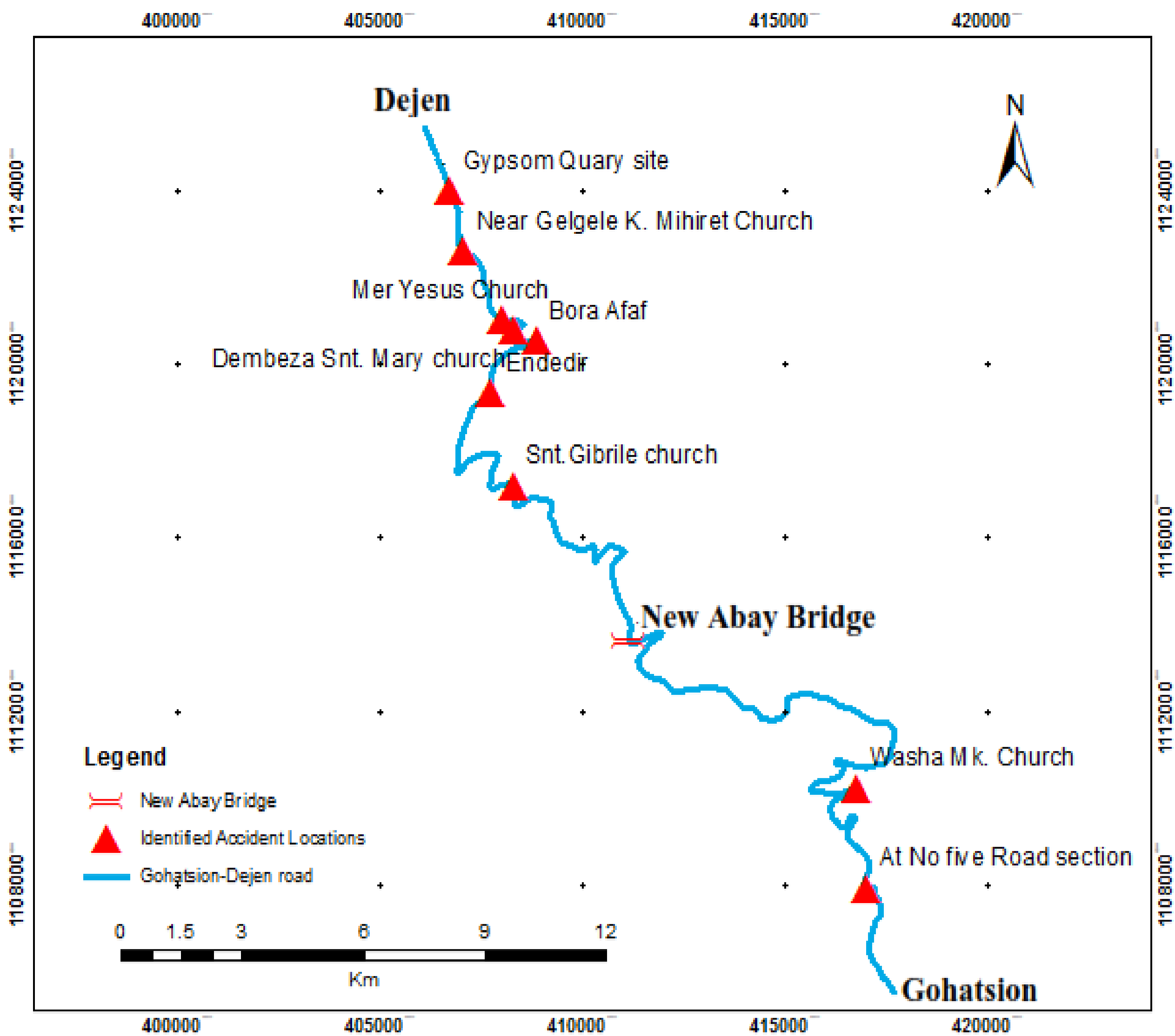


Figure 3.4: Identified accident locations along the case study area (Source: Arc GIS 10.4 Result).

3.9.2 Accident Data

The accident data which has been collected for this research includes accidents that occurred on a two-lane road segment from two police stations over the six-years study period and police commission offices have provided accident reports as paper copies from 2002-2007 E.C.

The police report data for an accident is a brief outline which gives information including date and time, location of accident, vehicles involved, vehicle information as well as driver, passenger and pedestrian information, a summary of the accident and accident scene diagram or traffic accident plan, and the final rest positions of the vehicles.

These reports have various codes for the vehicle type, alcohol and drug use, safety equipment used, severity level, road conditions (wet, dry or snow) at the time of accident, traffic control devices present, contributing causes concerning the driver/pedestrian and other similar information, all of which is intended to aid traffic police officers in explaining the accident events.

To take advantage of the database for traffic safety purposes, geometric measurements at accident locations have been extracted and recorded together with the traffic accidents for further analysis. The following are typical site photos taken at accident locations obtained from Gohatsion and Dejen Woreda police communication offices.

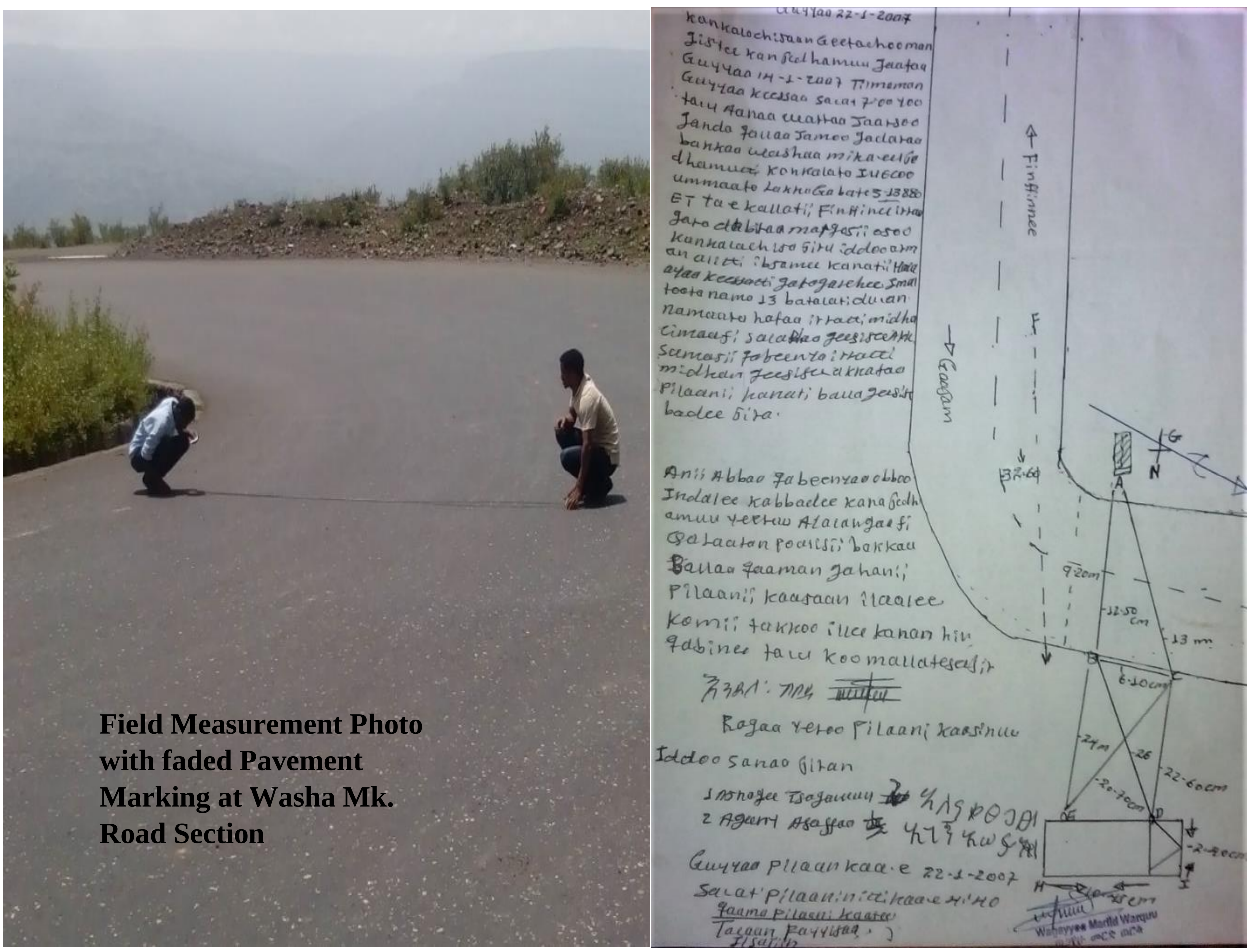


Figure 3.5: Traffic accident scene diagram at Kolla Jemo Gadera Kebele near to Washa Mikael Church (source: Gohatsion woreda police commission office).

Figure 3.6**:** Accident occurred due to oveturning at steep gradient of a curved section neat to Bora Afaf (Source: Dejen woreda Police Communication Office).

Figure 3.7: Accident occurred due to difficult down grade with worn-out pavement surface near to Dembeza Snt. Mary church.

Figure 3.8: Accident occurred due to over speeding at down grade near to Endedir.

Table 3.2: Number of accidents observed through various types of vehicles from 2002 to 2007.

Type of vehicles involved	Accidents occurred each analysis period							
	2002	2003	2004	2005	2006	2007	Sum	%
Car	2	4	1	3	6	3	19	6.30
Goods Vehicle	9	8	5	8	9	7	46	15.18
Bus/Mini Bus	26	28	15	28	20	30	147	48.51
Motor	2	1	1	2		1	7	2.30
Pickup	8	10	4	7	2	6	37	12.21
Cycle	1	2		1		3	7	2.30
Station Wagon	1	4	2	2	3	7	19	6.30
Others	2	1	2	10	5	1	21	6.93
Total	51	58	30	61	45	58	303	100

Source: Police Commission, Gohatsion and Dejen Woreda Road Traffic Accident Statistics Office.

Table 3.3: Annual Variation of accidents by their degree of severity.

Year (E.C)	Total No. of accidents	fatal	Injuries	PDO
2002	51	33	17	26
2003	58	25	93	32
2004	30	9	31	26
2005	61	17	20	31
2006	45	14	19	29
2007	58	60	126	44
Total	303	156	306	188

(Source: Police Commission, Gohatsion and Dejen Woreda Road Traffic Accident Statistics Office).

3.9.3 Vehicle Classification

Vehicle classification is an essential aspect of traffic volume. The types of vehicles are defined according to the breakdown adopted by ERA for traffic counts: cars; pick-ups and 4-wheel drive vehicles such as Land Rovers and Land Cruisers; small buses; medium and large size buses; small trucks; medium trucks; heavy trucks; and trucks and trailers. This breakdown is further simplified, for reporting purposes, and expressed in the five classes of vehicles (with vehicle codes 1 to 5).

Table 3.4: Vehicle Classification by class

Vehicle	Type of Vehicle	Description
1	Small Car	Passenger cars, minibuses (up to 24-passenger seats),Taxis, Pick-ups, and Land Cruisers, Land Rovers, etc.
2	Bus	Medium and large size Buses above 24 passenger seats
3	Medium Truck	Small and medium sized trucks including tankers up to 7 tons load
4	Heavy Truck	Trucks above 7 tons load
5	Articulated Truck	Trucks with trailer or semi-trailer and Tanker trailers

(Source: Road Asset Management and Contract Implementation Coordinate Directorate).

3.9.4 Traffic Data

Table 3.5: Annual Average Daily Traffic by Road Section and Vehicle Kilometer of Travel.

Year	VEHICLES CATEGORY					VEHICLE KILOMETER OF TRAVEL				
	Cars & Land R.	**Bus**	**Truck**	**Trucks & Trailer**	**Total**	**Cars & Land R.**	**Buses**	**Trucks**	**Trucks & Trailer**	**Total**
2002	182	320	446	139	1,087	7,462	13,120	18,286	5,699	44,567
2003	223	393	599	189	1,404	9,143	16,113	24,559	7,749	57,564
2004	263	464	740	230	1,697	10,783	19,024	30,340	9,430	69,577
2005	272	492	784	251	1,799	11,151	20,172	32,144	10,291	73,759
2006	286	472	842	266	1,866	11,726	19,352	34,522	10,906	76,506
2007	325	519	888	288	2,020	13,325	21,279	36,408	11,808	82,820
						63,590	109,060	176,259	55,883	404,793

(Source: "Traffic Survey and Safety Measures Report for Gohatsion–Dejen Road Project, Detailed Engineering Design, Tender Document Preparation and Construction (2014)'').

3.10. Data Collection

Data collection is carried out in two phases, Primary and Secondary data collections.

During secondary data collection, it was attempted to collect information from both published and unpublished sources which was relevant and important for the present study. The data, thus collected for the study includes:

- Traffic Accident Data
- Road Traffic Data
- Topographical Map
- Road Location Map
- Road Plan or Profile Data
- Road Cross-Section Data
- Road Geometric Element Data
- Traffic Accident Plan Data
- Traffic Safety Works Data
- Traffic Signs and Delineators etc.

A Summary of typical Road design and Drawing Catalogue where the above geometric data was taken is shown in the table below [52].

Table 3.6**:** As-built Road Drawing Index

Section	**Drawing No.**	**Tittle**
A.GENERAL	A-1/2	Drawing Index
	A-2/2	Location Map
B.ROAD	B-2/332-B-41/332	Horizontal Alignment
	B-42/332-B-81/332	Plan
	B-82/332-B-132/332	Profile
	B-135/332-B-138/332	Typical Cross Section
	B-161/332-B-164/332	Traffic Safety Work
	B-165/332-B-174/332	Cross Section
	B-199/332-B-238/332	Arrangement of Guard Post
	B-252/332-B-291/332	Arrangement of Marking
	B-292/332-B-331/332	Arrangement of Warning Sign
D.ROAD RENOVATION WORKS	D-1/13-D-7/13	Plan
	D-8/13-D-13/13	Cross Section

(Source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2009).

3.10.1. Field Work Activities

During the field observation, it was necessary to begin by conducting visual inspection and site inventory of the whole stretch of the Gohatsion-Dejen Road segment in order to get more information and impact about the road structure and its existing condition.

All relevant information and data pertaining to the road and its geometric condition, type and number of traffic signs and delineators present, road markings, and other traffic safety works of the area were collected through the initial field visit activities of the present study. Some data were also collected by informal interviewing of road users, drivers, Gohatsion and Dejen woreda traffic police officers and site engineers.

According to the information from the people, the road structure could be one of the factors that trigger frequent accident events at different times for the selected case study area. This information from the people helped to put emphasis on the road geometric constituents in comparison to design values of an as built road to understand the impact of design elements on traffic safety, as it could be one of the major causative factors for traffic accident problems encountered.

Furthermore, a visual site visit was made to know the performance of the road, and hazardous road sections were identified depending on the degree of their traffic accidents indicated in the traffic police records and photographs were also taken to show the existing geometric condition.

Figure 3.9: Field measurement photos taken at No. five road section.

3.10.2 Traffic Safety Features

Since projects at the planning stage by their nature have little information about the details of design, it is vital that the designer should incorporate important safety elements during the preliminary and detail design stages.

Regarding to the subject, none of the existing road sections selected for the case study have complete traffic safety features at the entry as well as exit of adverse geometrical structures which implies that there is a potential safety problem.

Some characteristic safety problems, which are not fulfilled to the present road alignment, and their recommended safety measures are indicated below in order to improve the safety of the road and minimize accident occurrences.

i) General Problems Observed During Field Work Activities:

- The roadway has adverse geometric alignment, particularly with respect to sharp horizontal curves and steep grades to the vehicle's maneuvering position as shown in the following photo.

Figure 3.10: Field photo with a sharp horizontal curve and difficult downgrade at Gelgele section.

- Some Traffic signs are poorly located and obstructed by trees, cliffs and mountains.
- The number and type of regulatory and warning signs provision and placement are not as per the road layout.
- The centerline as well as the edge markings are worn out and barely visible throughout the roadway length.
- Bad wearing surface with visible pavement distresses is observed throughout the stretch.

Figure 3.11: Field measurement photo wtith bad wearing surface at Dembeza Road section.

- No or few traffic signs are placed before the beginning of many difficult curves.

Figure 3.12: Field photos with damaged traffic signs and wornout pavement surface.

- The approach roadway alignment to the new Abay Bridge on the Dejen side has an adverse geometric alignment passing through a sharp curved section having a horizontal radius of 35m with a vertical grade of 6.9% and super elevation of 8% and the approach roadway alignment on the Gohatsion side has a horizontal radius of 55m with a vertical grade of 6% and super elevation of 6.9% which is the main cause of traffic accident and delay.

Generally, as per the safety evaluation of the existing road with respect to geometric alignment, sight distance, change in roadway width, and absence of other traffic safety features, the following safety problems are observed according to the guidelines set under ERA and AASHTO manuals.

Roadway Width Constriction: there is a width constriction on some parts of the existing road due to edge failure which is the main cause of traffic accident and delay. The traffic coming from one side has to give way for the opposite one with full turning ability, otherwise accident will happen. The situation will get worse while driving at night because of the absence of advance warning signs. AASHTO recommended to widen the existing roadway width on the inside edge to ensure good vehicular maneuvering and smooth transition of vehicles from adverse curved sections to the tangents.

Traffic Safety Marking: Markers are erected so that they appear as a continuous line to the motorist and the chevrons indicating the direction of travel. Pavement markings should be provided along the centerline and edges with no overtaking lines on the roadway alignment. Solid yellow line marking should also be provided for all edges of the pavement to delineate the edge of the road so that it is visible for drivers to decide on.

Safety Barriers: It is recommended to install safety barriers for areas having deep gorges which is provided for slopes >1:4 and /embankments >2m with ends tapered from road (as per ERA Manual, 2002) and should be adequately marked by painting or use of other high-visibility materials to decrease the psychological consequences of both drivers and passengers.

Regarding Steep Gradient at Difficult Curves: The literature review findings reveals that road sections located on sag vertical curves with steep grades at hazardous geometric sections are vulnerable to traffic accidents because of increasing speed and losing control of vehicles.
Drivers (especially those with heavy vehicles) should have enough information about the grade's profile before starting their descent to be able to adjust their speed right from the top, and by consequence, to avoid difficult deceleration maneuvers midway down [38].

Traffic signs must not be located too far from the beginning of the slope as to diminish their credibility. The recommended distances should be adapted to the operating speed.

Warning signs should be located from 25 m (30 km/h) to 200 m (100 km/h), before the beginning of the descent [51]. It is also recommended to provide rumble strips along the roadway to alert drivers about possible dangers by causing a tactile vibration and audible rumbling, transmitted through the wheels into the whole body of the car. They are mostly applied across the travel lanes to alert drivers of the possible dangers so that they reduce speed and found to be more effective for alerting drivers on steep gradient.

Presence of Sharp Horizontal Curves: Features such as sharp curves aren't easy for a driver to identify especially for unfamiliar drivers. In such a case there is a greater chance of a wrong decision to be made which leads to traffic accidents. It is recommended to do a curve widening and eliminate the sharp curve but in the meantime it is important to place advance warning signs ahead of the curve. The curve sign is used in advance of a substandard or hidden curve and shoulder where possible be combined with an advisory speed sign.

All regulatory and warning signs should be properly designated and placed in advance.

The following warning sign is not good for new driveres passing through the difficalt Nile Gorge.

Figure 3.13: Dangerous warning signs with posted speed limits at Abay Gorge.

3.11 Method of Data Processing and Analysis

This study seeks to find answers to the problems through the analysis of casual relationships between traffic accident and road geometric characteristics such as horizontal alignment (curves), vertical alignment (grades), super elevation.

The general procedure followed for the analysis of the data, primarily consists of performing statistical correlation analysis coupled with subjective evaluation. Statistical correlation analysis was adopted to determine whether the dependent variable (rate of traffic accidents) was significantly related to the independent variables (Gradient, Radius, Carriageway Width, and Super elevation) using the relative importance of these factors. Exploratory data analyses were conducted using Microsoft Excel to investigate interactions and checking of assumptions underlying the use of regression analysis techniques, specifically using scatter and linear plots of the data. This was followed by inferential analysis and subsequently interpretation of results as well as drawing valid conclusions. Accident data extracted from the case study sites were used to validate the statistical regression model. It is important to state that for all analysis P-value < 0.05 was considered to be statistically significant.

CHAPTER FOUR

DATA ANALYSIS AND EVALUATION

4.1 Traffic Accident Distribution

A Statistical Result visualized in Figure 4.1 below shows the total number of accidents distributed over the six years of analysis period. It is understood that the number of years and traffic volume exhibit an influence on the accident situation.

The most significant feature of the chart is that the number of road traffic accidents in the subject area are increasing as years go by except a significant reduction observed in 2004 and 2006 with a total number of accidents being 30 and 45 respectively. In 2002 there were 51 accidents, this was increased to 58 in 2003. However, there was a sharp increase in 2005 with a total number of road traffic accidents being 61. This observation support what many researchers stated so far that as years go by, the number of vehicles will be increasing and the number of traffic accident increases accordingly and as such the number of people who are likely to be killed in road accidents will surely increase.

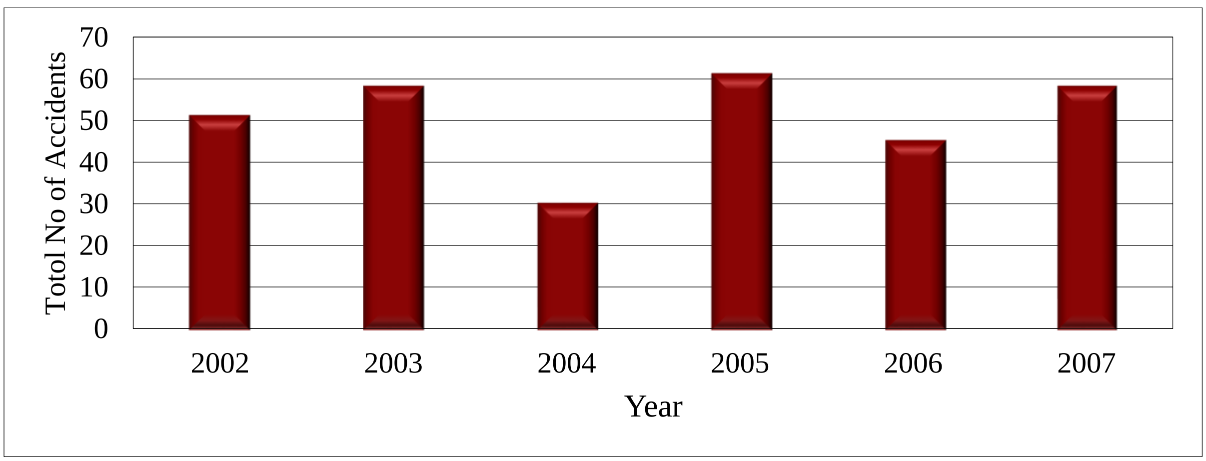


Figure 4.1: Total number of accidents distributed over the six years of analysis period.

The chart below shows the annual variation in accident's severity of the total stretch during the years 2002-2007. It is observed that severity of accidents are increasing relatively in most of the years. However In the year 2004 the degree of accident severity was low and high in the year 2003 and 2007. It may be due to an increase in the no of vehicles, bad traffic environment, and increase in night driving.

Injuries are the dominating types of accidents constituting the highest variations in accident's degree of severity (47.1%) followed by PDO (28.9%) and Fatal (24%) types as shown below.

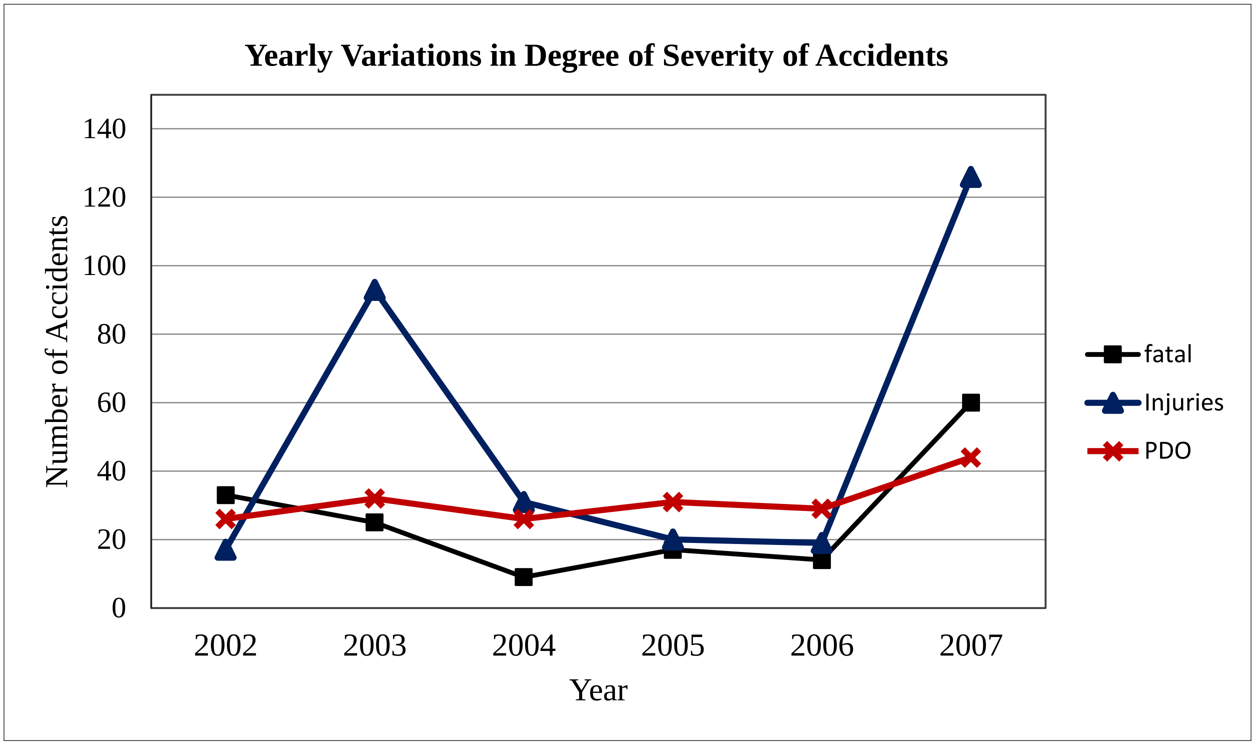


Figure 4.2: Distribution of accident severity over the analysis period.

The total number of accidents occurred by various types of vehicles in Gohatsion-Dejen road segment is shown in the figure 4.3 below.

The chart clearly shows that Mini Buses/Buses, Goods Vehicles and Pickups are the three major causes of road traffic accidents of the subject area. The Buses and Mini Buses are known to be the major carriers of people in all corners of the country followed by cars, goods vehicles, motor cycles, pickups, cycle and the heavy duty vehicles.

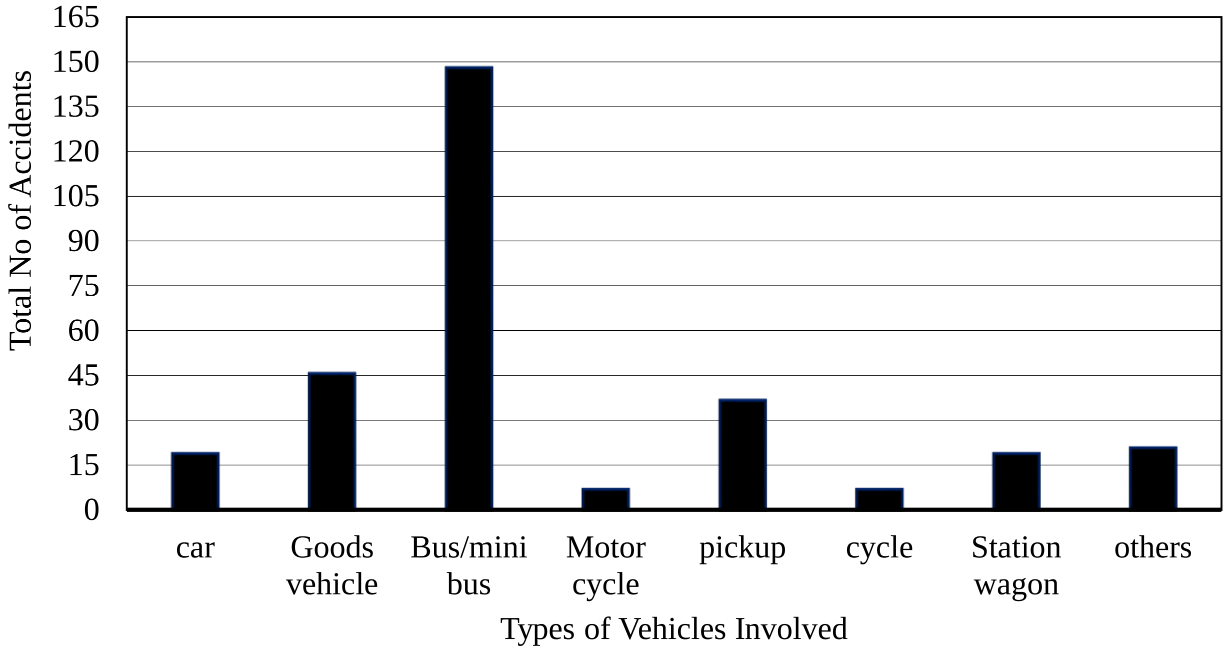


Figure 4.3**:** Total number of accidents occurred by various types of vehicles

The percentage distribution of traffic accidents occurred in the case study area due to various types of vehicles involved in road accident from 2002-2007 are presented in the figure 4.4 below.

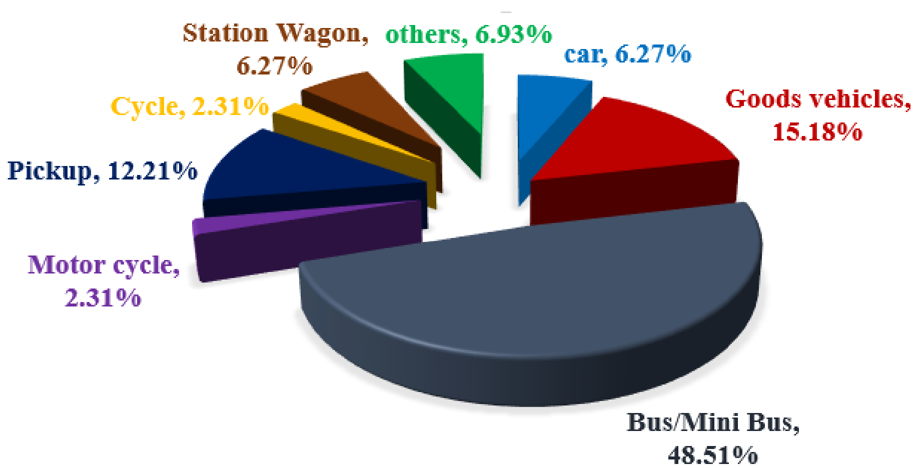
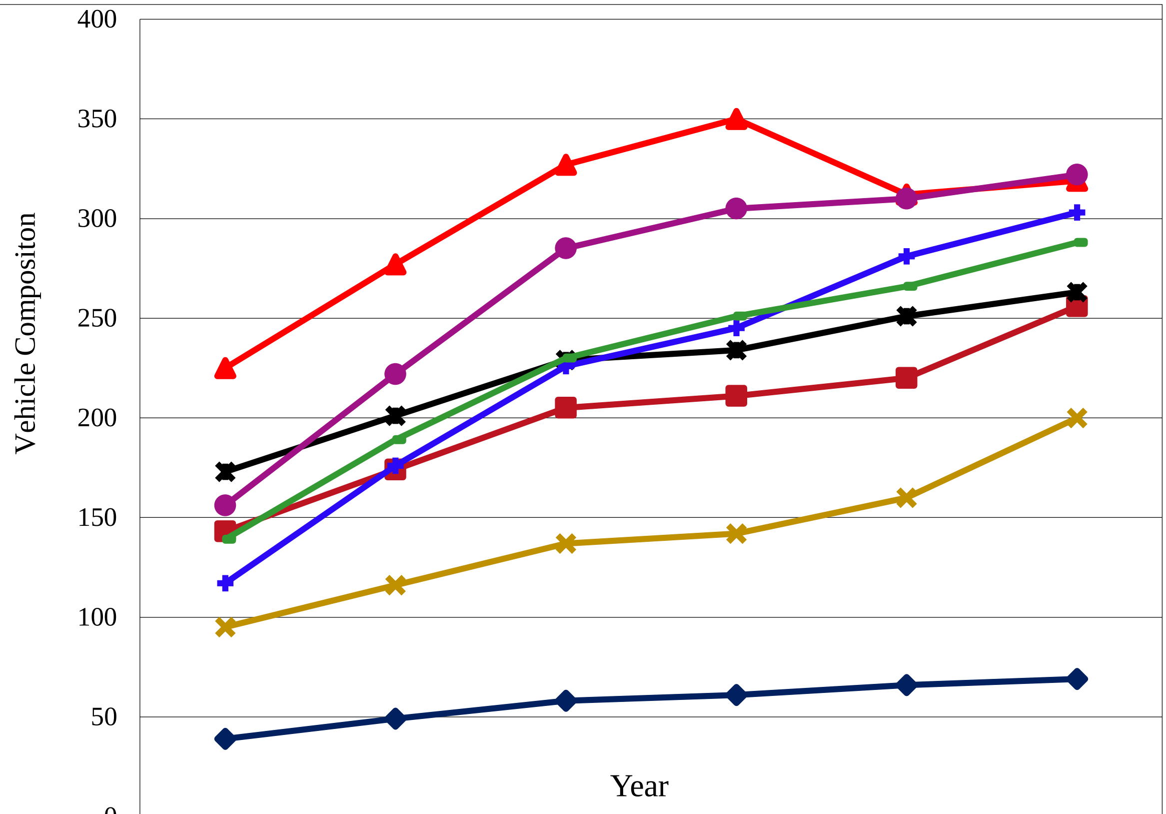


Figure 4.4 Percentage Distribution of accidents per vehicles involved

By dividing accidents according to vehicle types involved, Figure 4.4 shows that Buses/Mini Buses and Goods Vehicles were the dominating vehicle types representing 48.51% and 15.18% respectively followed by Pickups, Others, Cars and Station Wagon, and Motor Cycle/Cycle.

4.3 Traffic Data Analysis

From the Figure 4.5 shown below, Consideration of the pattern of composition of traffic on the road network of the study area clearly shows that the lion share of traffic moving on the main trunk road across the Gohatsion–Dejen Road segment is Small Buses. A distinct tendency for traffic composition of small Buses to decrease with increasing the traffic year was observed after the year 2005. This may be due to the restriction of Mini Buses after 2005 not to cross from one region to the other for long driving distances (e.g. Dejen to Addis) because of their history of frequent traffic accident records in the subject road. Due to the current construction activity of the Ethiopian Renaissance Dam and existence of the newly constructed Abay Bridge, the number and types of trucks using the road have also been substantially increased in transporting heavy goods, machineries and other construction materials passing through the difficult Nile Gorge. Previously, large trucks were avoided using this road for fear that the old bridge may collapse, but after the construction of the new Renaissance Abay Bridge, there is no need to restrict vehicles one side at a time. The type of vehicles which took the least number of traffic composition for the years under consideration were Cars prior to Large Buses as shown in the figure below.



	2002	2003	2004	2005	2006	2007
Cars	39	49	58	61	66	69
Land Rover	143	174	205	211	220	256
Small Buses	225	277	327	350	312	319
Large Buses	95	116	137	142	160	200
Small Truck	173	201	229	234	251	263
Medium Trucks	156	222	285	305	310	322
Heavy Trucks	117	176	226	245	281	303
Trucks & Trailers	139	189	230	251	266	288

Figure 4.5: Distribution of Annual Average Daily Traffic over the analysis period.

The risk of road traffic accidents varies with respect to Average Daily Traffic on the road. This may agree with the findings revealed by many literatures that although a road section with little traffic flow causes less number of accidents, it could be more dangerous than the same with more traffic. As shown in fig 4.6, traffic accident is high in the highest traffic volume except a significant reduction in 2004 and 2006 due to the fact that some vehicles like mini busses were restricted not to use the route because of their catastrophic accident records.

It may also be due to faulty design and operational features of highway and influence of other parameters like roadside features and bad geometrical setup of the study area.

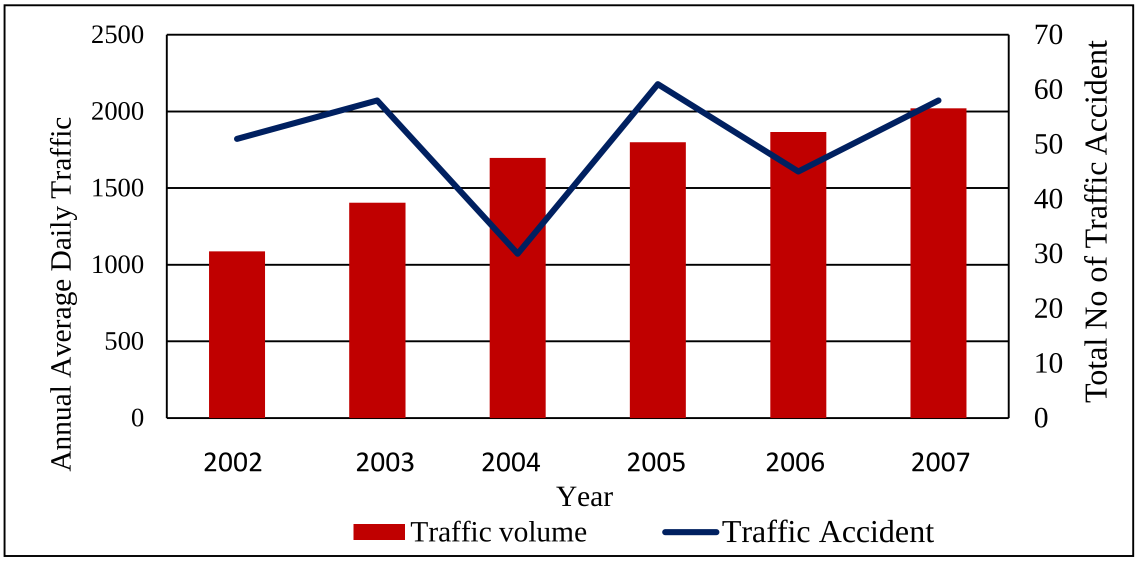


Figure 4.6 effects of AADT on Traffic Accident through the analysis period.

4.4. Variation of Accident Rates with Road Geometric and Traffic Factors

As it has been stated in the Highway design and traffic safety engineering handbook that accident rate (AR) considers the geometric components and traffic volume to allow a direct comparison of different roadway sections with respect to traffic safety at the selected sections. This study have been conducted on how the rate of accident is affected by the radius of horizontal curve (RH), vertical curve (RV), super elevation (e), Carriageway width and traffic volume.

Rate of accident is the ratio of "total no. of accidents" and the "total no. of vehicles" passed on a particular road section during the same period of time. It is in accident per Million Vehicle Kilometers (MVKm) as given in the equation below [20].

$$\mathbf{AR} = \frac{\mathbf{Accident} * \mathbf{10^6}}{\mathbf{AADT} * \mathbf{365} * \mathbf{T} * \mathbf{L}}, [\mathbf{20}] \qquad (4.1)$$

Where, AR = Accident rate (MVKm)

AADT = Average annual daily traffic.

L = Length of investigated section (41km)

T = length of investigated time period (6 yrs.)

365 = number of days/yr.

After determining AR; statistical methods have been used to analyze the processed data including histogram graphs and linear regression analysis tools.

In the whole examination periods, Figure 4.7 below shows that AR is high in the first two years following a significant reduction of the remaining analysis periods.

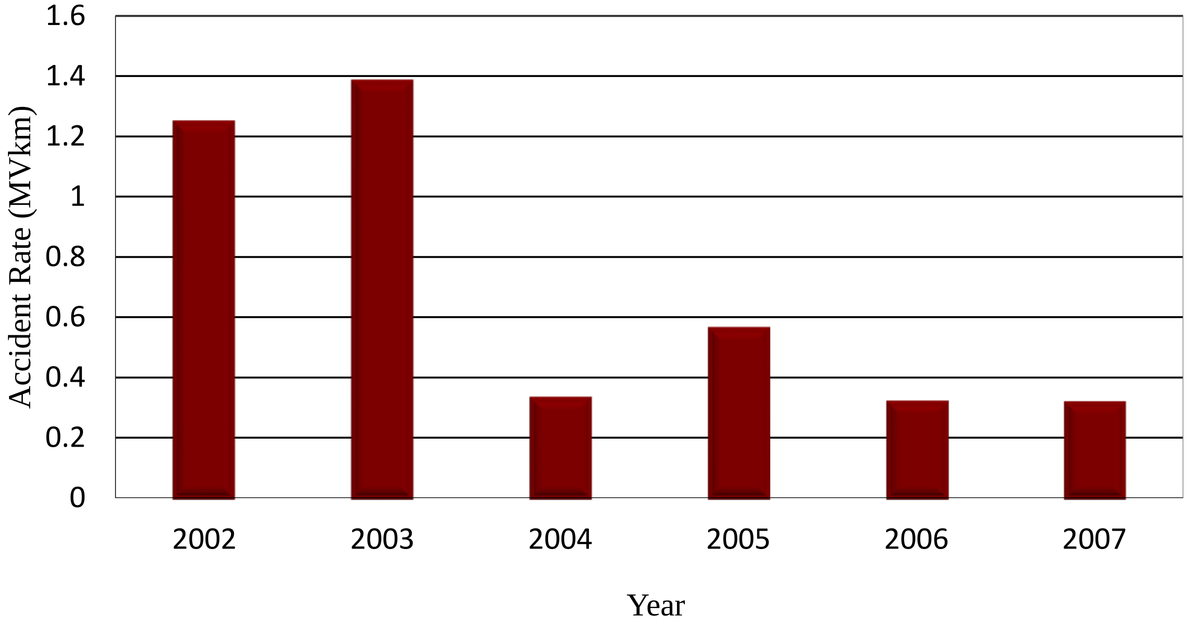


Figure 4.7: Accident rate Distribution through the analysis periods.

4.5 Scatter Plot

Prior to carrying out the regression analysis, a scatter diagram was generated by applying Microsoft Excel Spreadsheet, in order to study the relationships developed between the dependent and independent variables and determine the model that best suits the sampling results. Consequently, the scatter plot of different parameters are presented below from.

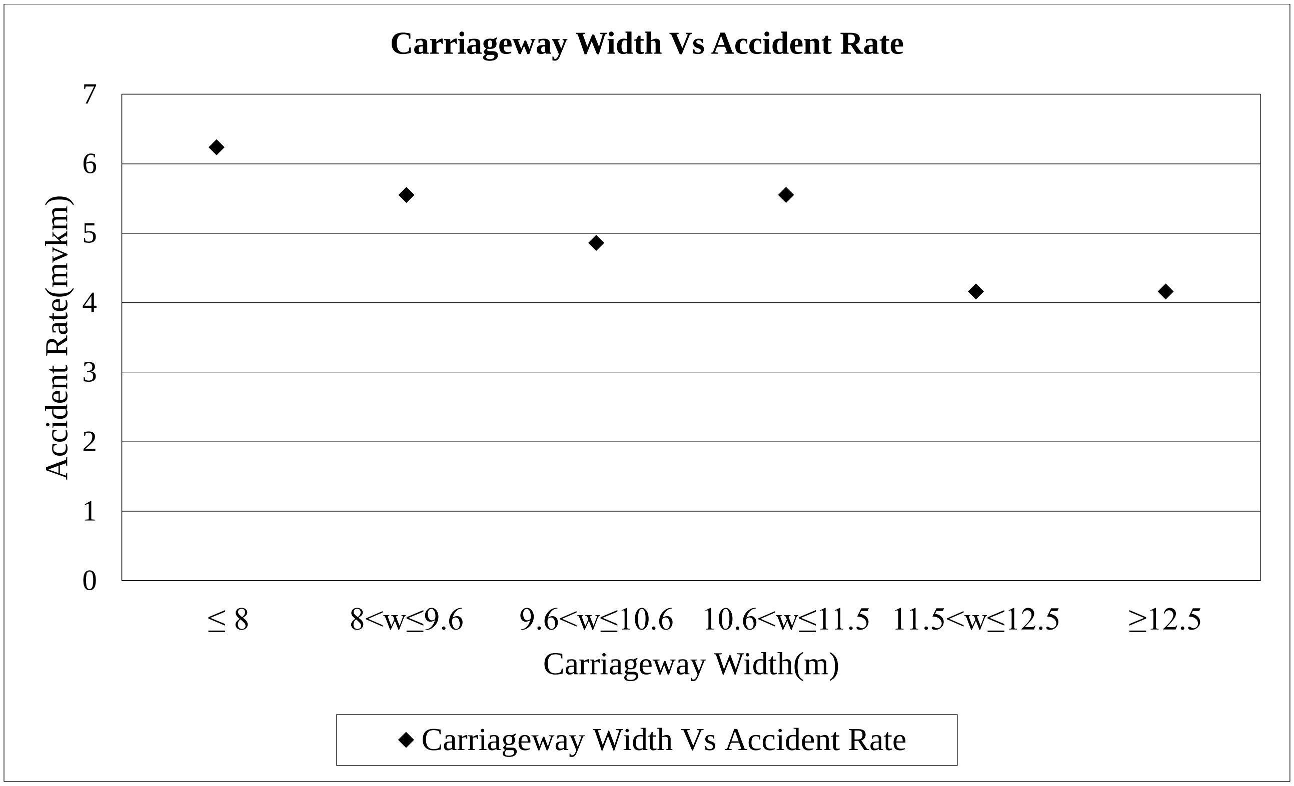


Figure 4.8: Scatter Diagram of Carriageway Width versus Accident Rate

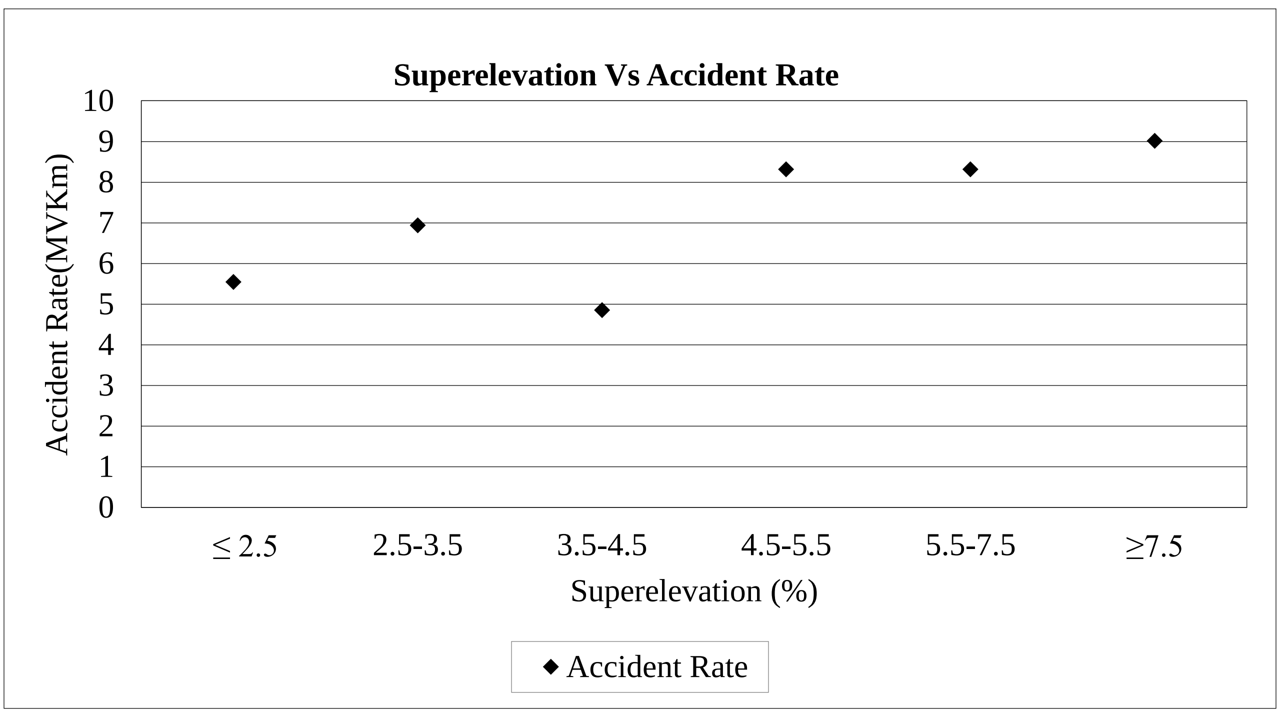


Figure 4.9: Scatter Diagram of Super elevation versus Accident Rate

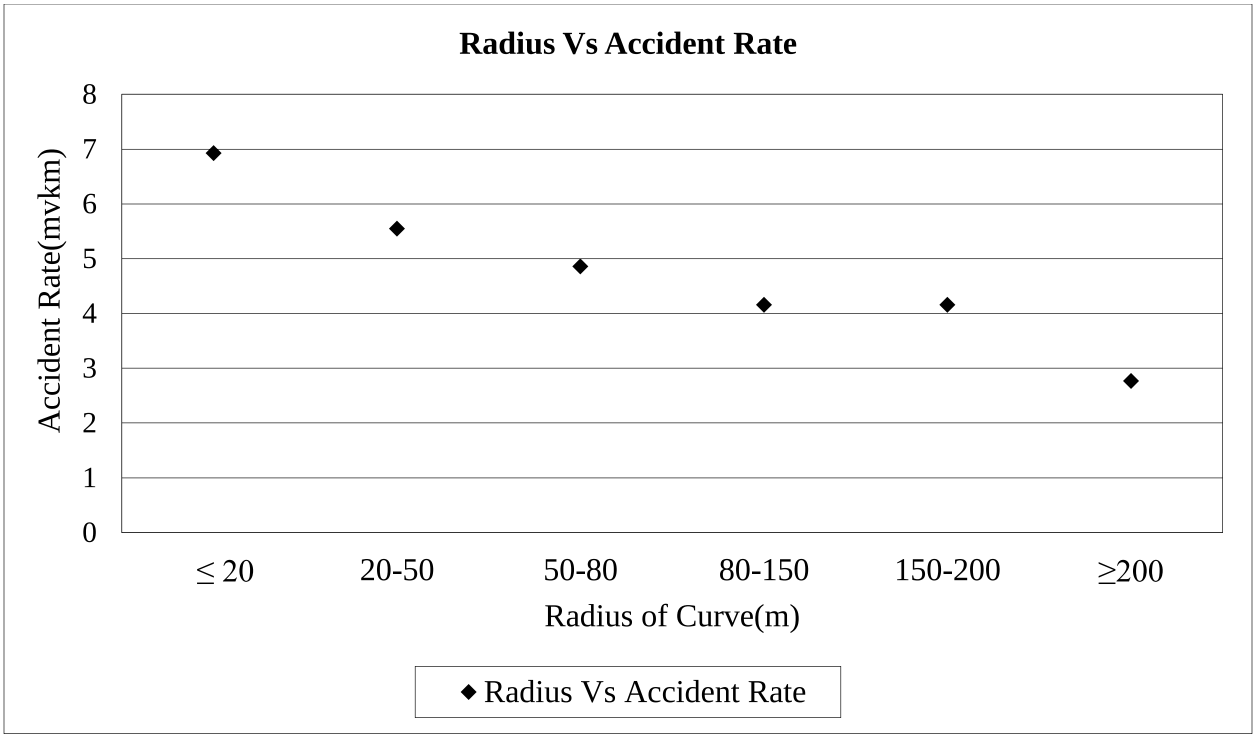


Figure 4.10: Scatter Diagram of Radius versus Accident Rate

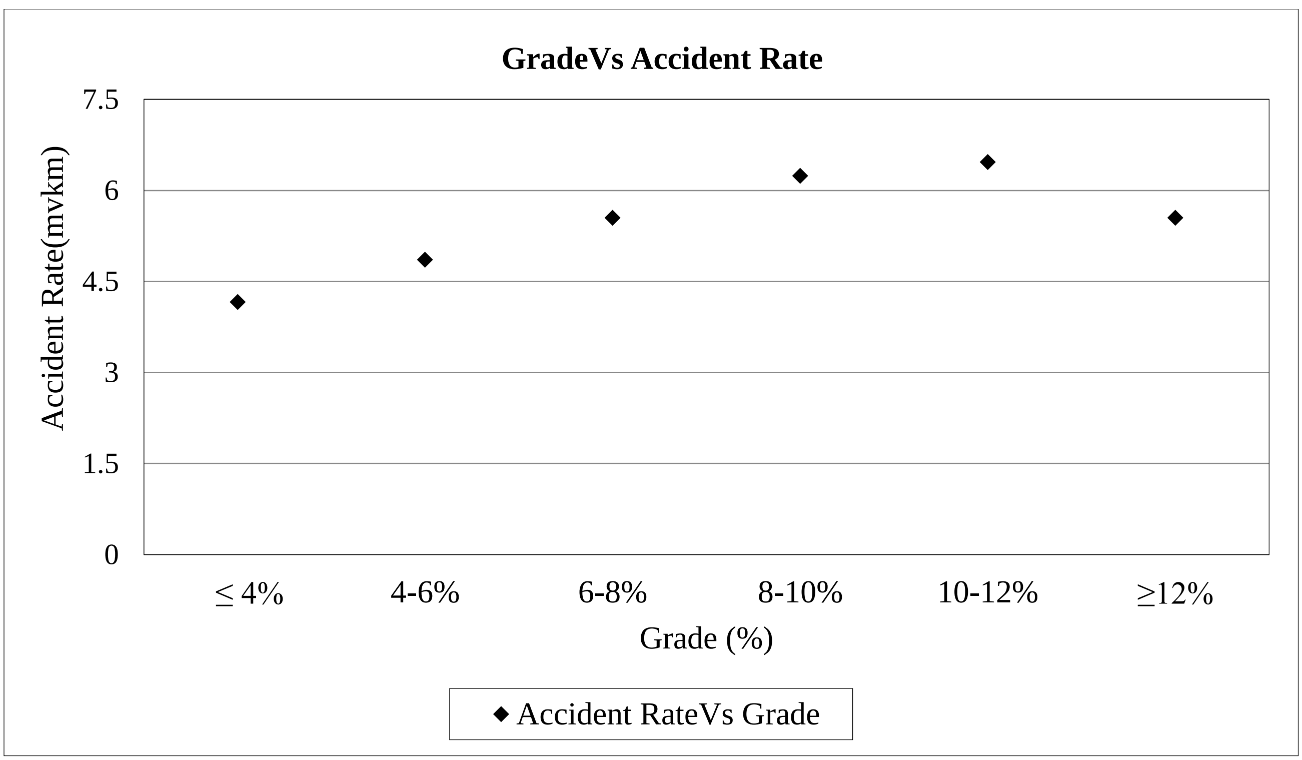


Figure 4.11: Scatter Diagram of Grade versus Accident Rate

The above scatter diagrams provide a visual method of displaying a relationship between variables as plotted in a two dimensional coordinate system. Inspection of the scatter diagrams indicate that, although no simple curve will pass exactly through all the points, there is a reasonable indication that the points lie scattered randomly around a straight line, particularly for the carriageway width, radius of curvature, grade and super elevation and straight-line fit is suggested.

Relatively the above scatter plot shows a linear response and hence, a linear regression model expresses the association between the subject parameters. A linear relationship is usually practiced in solving different engineering problems because of its simplicity.

4.6 Regression Analysis

Regression analysis is a statistical method for modeling the relationship between two or more variables using simple and multiple linear equations [20].

Simple linear regression refers to a regression on two variables while multiple linear regressions refers to a regression on more than two variables.

The general equations of a probabilistic single and multiple linear regression models are presented in the following forms [20].

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{4.2}$$

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 \ldots + \alpha_n x_n + \varepsilon \tag{4.3}$$

Where, the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients α_0, α_1, $\alpha_2 \ldots \alpha_n$ are termed as multiple regression coefficients which is also applied in this study. The standard error term (ε) is used to estimate the dispersion of prediction errors when it is needed to predict dependent values from the independent variables in a regression analysis [22]

The basic assumption to estimate the regression coefficients of the single regression model is based on the least square method. The correlation coefficient R^2 only gives a guide to the "goodness-of-fit" or how closely variables X and Y are related. It does not indicate whether an association between the variables is statistically significant.

Confidence of the result indicates in terms of significant value (P). The correlation was considered significant if (P) is zero or 5 % different from zero [23]. From the (SPSS) statistical output, pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Effects of driver characteristics haven't been considered in the analysis due to insufficient information. Specific to this research, (SPSS) software is employed to investigate the significance of individual variables.

Single and Multiple Linear Regression Analysis techniques are adopted in this research since they are the most widely used and economical types of mathematical models for studying the relationships among the variables of a given data and predict the influence of independent variables over the dependent one.

The correlation among input variables is tested; the results are shown in Table 4. 1. The results of coefficient of correlation (R) which gives the strength and direction of the relationship, and coefficient of determination (R^2) which is a guide to the "goodness-of-fit" or how closely variables X and Y are related show that there is a high correlation between accident rate and other input variables. This indicates a good relationship between dependent and independent variables.

To identify the influence of one variable on the other, a stepwise linear regression has been analyzed and as a result, the respective correlation coefficients and level of significance are determined for each variable as shown below. The following relationships have been drawn between the elements of road geometric design and traffic-related variables and rate of traffic accidents.

Thus, the linear regression results of different parameters are presented below from Figure 4.12 to Figure 4.16:

4.6.1 Single Linear Regression Analysis

Model 1: Correlation between Accident Rate (AR) and Radius of Horizontal Curve (R_h).

The rate of road traffic accident varies with respect to the variation of horizontal curve Radius as shown in figure 4.12. Accident Rate is high in the lowest Radius of Curve and decreases with increasing in Radius.

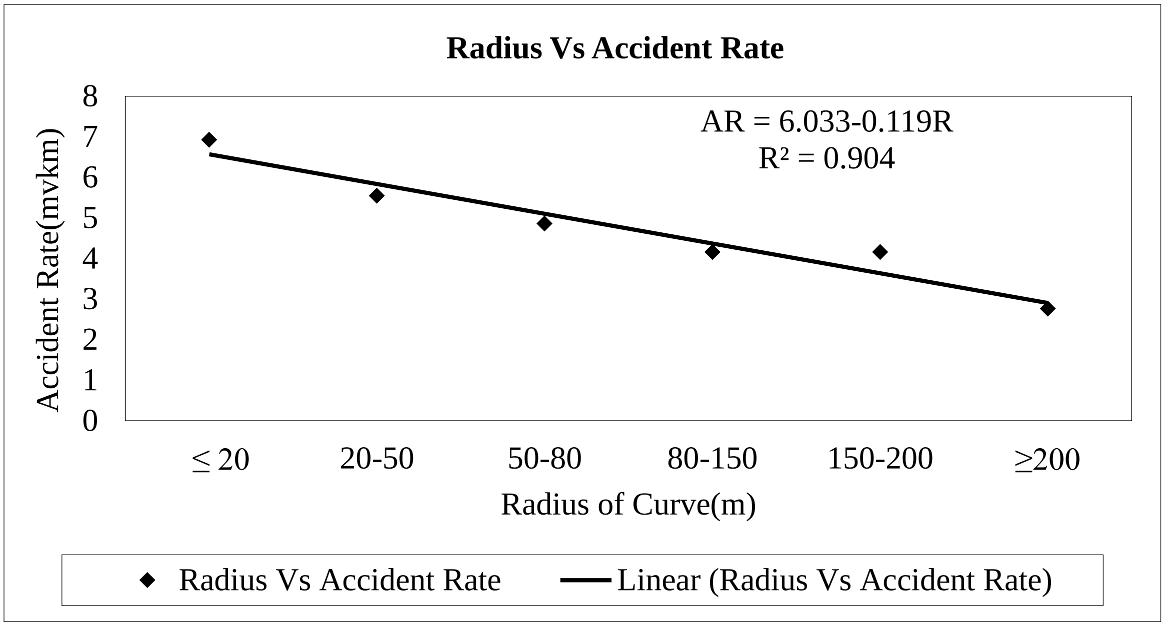


Figure 4.12: Influence of Curve Radius on Accident Rate

The resulting regression analysis after correlating AR with Horizontal Curve Radius (R_h) is expressed by the following single linear equation with its corresponding correlation coefficients:

AR = 6.033 - (0.0119 * R) with**,**

R = 0.951, R^2 = 0.904, Adj. R^2 = 0.872, and Standard error of Estimate (ε) **=** 0.369.

	Coefficient	**Std. Error**	**t**	**P**	**Standard Coefficient**
Constant	6.033	0.366	16.502	<0.001	
R	-0.0119	0.00223	-5.312	0.013	-0.951
Analysis of Variance:					
	DF	**SS**	**MS**	**F**	**P**
Regression	1	3.847	3.847	28.219	0.013
Residual	3	0.409	0.136		
Total	4	4.256	1.064		

The details of the statistical out-put indicates that the relationship developed between Radius and Accident Rate is significant ($p<0.05$) with the highest R^2 value.

Model 2: Correlation between Accident Rate (AR) and Super elevation (e).

- Super elevation values of between 3.5 and 4.5 percent exhibited the most favorable results.
- Accident rate increases significantly for super elevations greater than the favorable result.
- Super elevations ≥ 7.5 percent have the greatest accident rates.

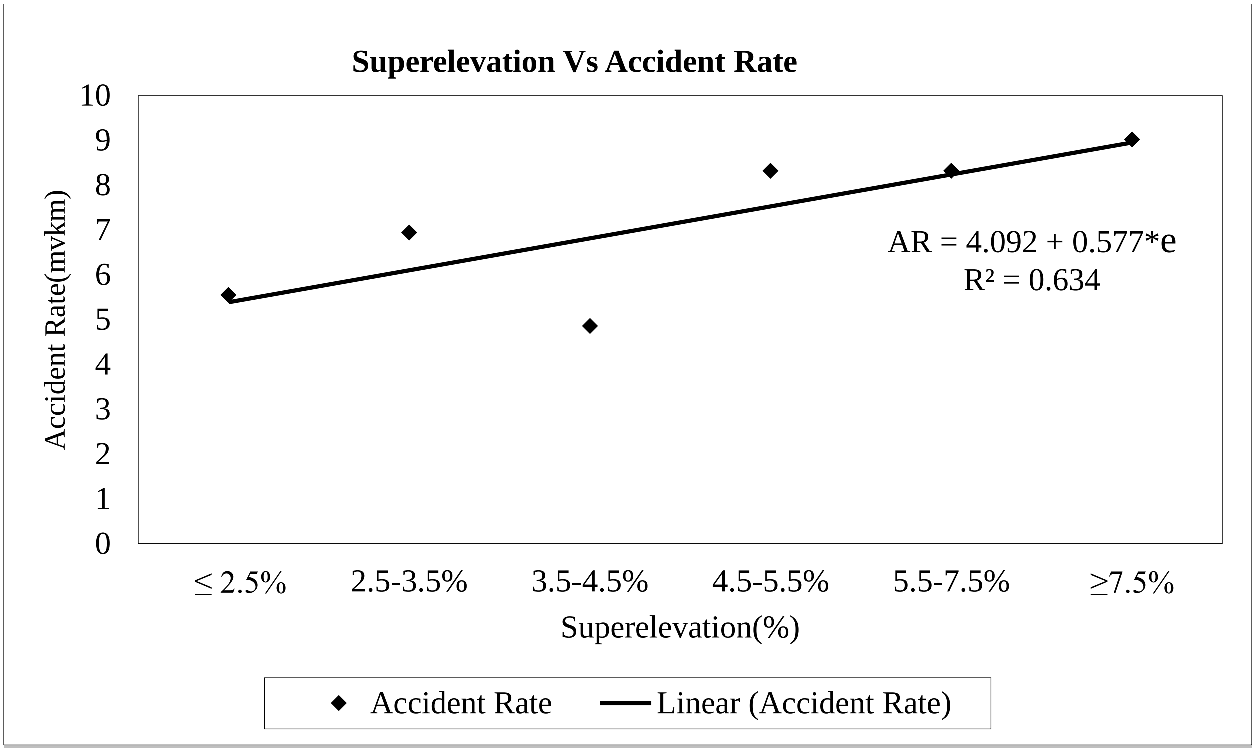


Figure 4.13: Influence of super elevation on Accident Rate

The resulting regression analysis after correlating AR with Super elevation is expressed by the following single linear equation with its corresponding correlation coefficients:

AR = 4.092 + (0.577 * e), with

R = 0.796, R^2 = 0.634, Adj.R^2 = 0.543, and Standard error of Estimate = 1.135.

	Coefficient	Std. Error	t	P	Standard Coefficient
Constant	4.092	1.257	3.255	0.031	
e	0.577	0.219	2.633	0.058	0.796

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	8.928	8.928	6.931	0.058
Residual	4	5.152	1.288		
Total	5	14.081	2.816		

The details of the above statistical out-put indicates that the relationship developed between Super elevation and Accident Rate is not significant (P>0.05 with moderate value of R^2.

Model 3: Correlation between Traffic Accident and Annual Average Daily Traffic (AADT)

The risk of road traffic accident varies with respect to Average Daily Traffic on the road. It was found that accident rate increases with increase in AADT as shown in the figure below.

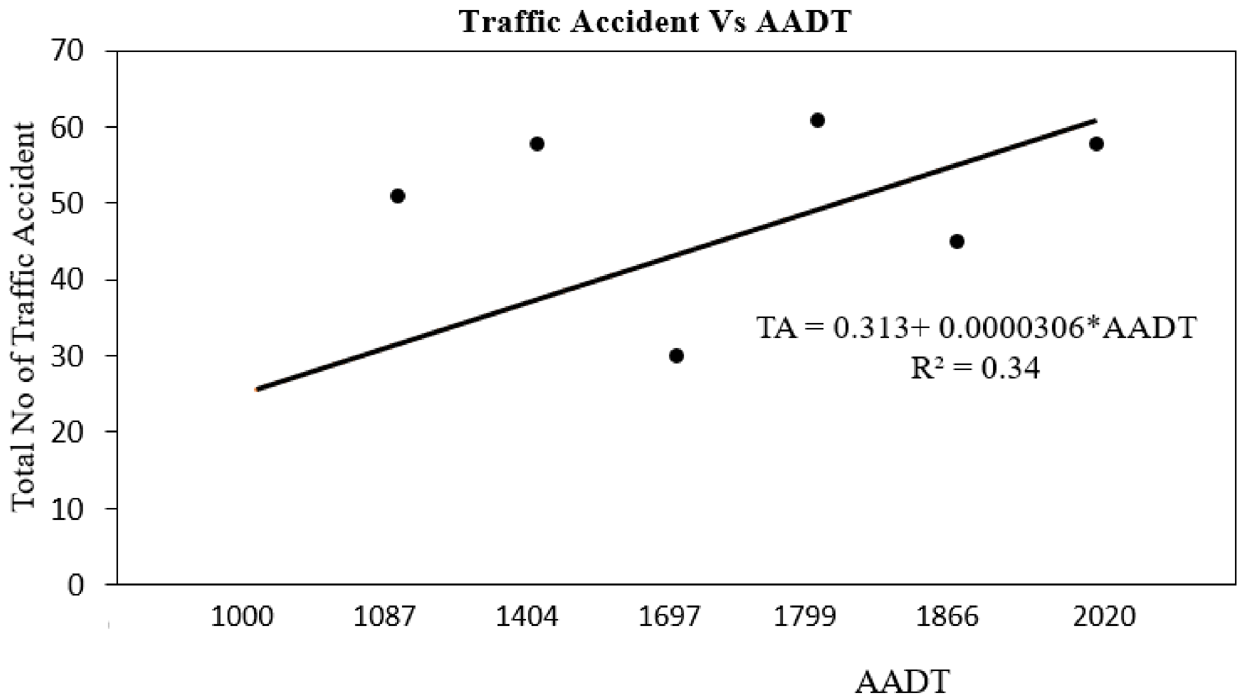


Figure 4.14 Effects of Annual Average Daily Traffic on Accident.

The resulting regression analysis after correlating Traffic Accident with AADT is expressed by the following single linear equation with its corresponding correlation coefficients:

TA = 0.313 + (0.0000306 * AADT) with R = 0.583, R^2 = 0.340, Adj R^2 = 0.175 and Standard Error of Estimate = 0.016.

	Coefficient	Std. Error	t	P	Std. Coeff.
Constant	0.313	0.0357	8.777	<0.001	
AADT	0.0000306	0.0000213	1.435	0.225	0.583

Analysis of Variance:

	DF	SS	MS	F	p
Regression	1	0.000547	0.000547	2.058	0.225
Residual	4	0.00106	0.000266		
Total	5	0.00161	0.000322		

The details of the statistical out-put of Model 3 indicates that the relationship developed between Traffic Accident and AADT is not significant (p>0.05). Besides, the R^2 value is too low.

Model 4: Correlation between Accident Rate (AR) and Vertical curve (G).

The influence of road traffic accident varies with respect to the variation of Vertical curve as shown in fig 4.15, accident rate is low in the lowest percentage of grade and increases with increasing in grade. Vertical Curve value ≤ 4% was considered to be the minimum result for accident rates.

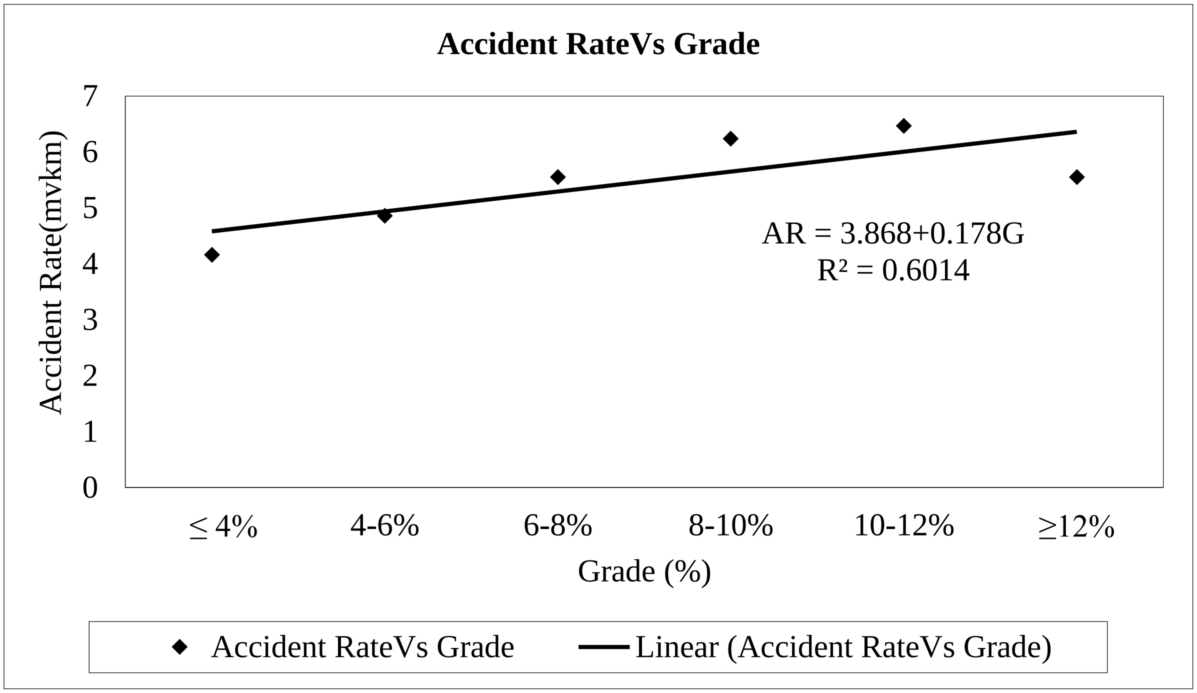


Figure 4.15: Influence of Grade on Accident rate

The resulting regression analysis after correlating AR with Vertical Curve (G) is expressed by the following single linear equation with its corresponding correlation coefficients:

AR = 3.868 + (0.178 * G), with

R = 0.775, R^2 = 0.6014, Adj. R^2 = 0.502, and Standard error of Estimate = 0.607

	Coefficient	Std. Error	t	P	Standard Coefficient
Constant	3.868	0.698	5.542	0.005	
G	0.178	0.0725	2.457	0.070	0.775

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	2.221	2.221	6.035	0.070
Residual	4	1.472	0.368		
Total	5	3.694	0.739		

The details of the statistical out-put indicates that the relationship developed between the Vertical Curve (G) and AR is low with insignificant standard value of ($p>0.05$).

Model 5: Correlation between Accident Rate (AR) and Carriageway Width (CW).

A distinct tendency for accident rate to decrease with increasing Carriageway width greater than 8 m as shown in figure 4.16. Road categories with $W \leq 8.0$m had the highest accident rate.

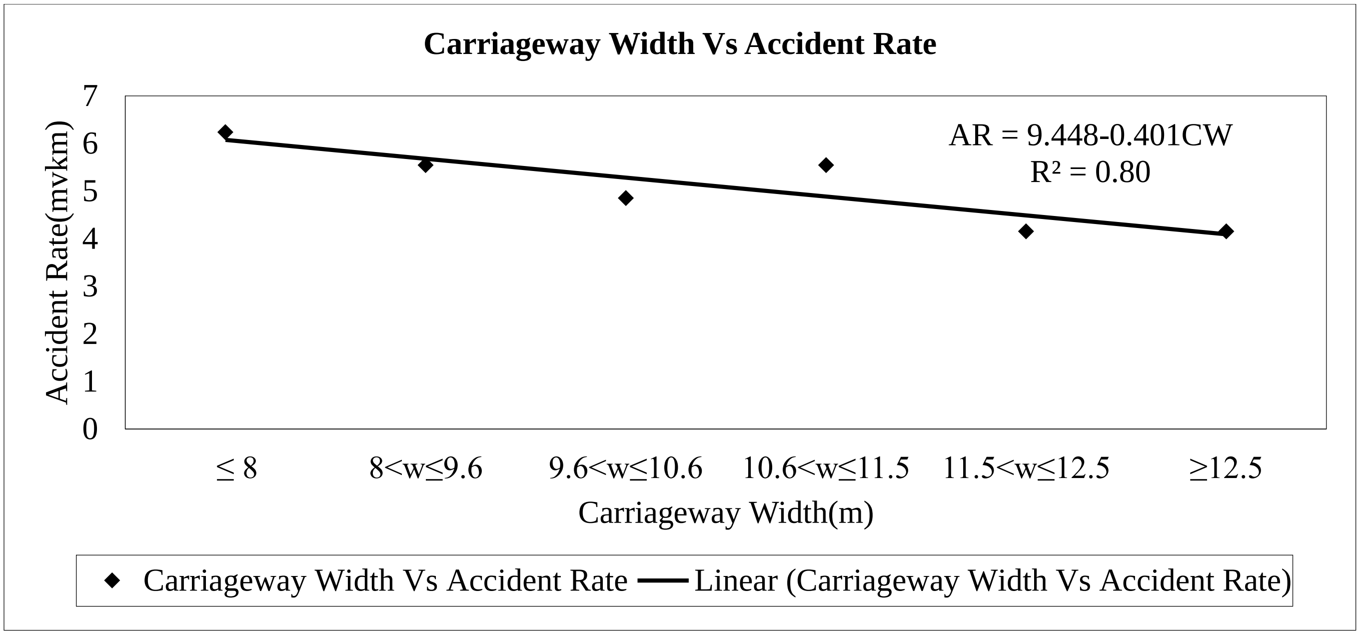


Figure 4.16: Influence of Carriageway Width on Accident Rate

The resulting regression analysis after correlating AR with Carriageway Width (CW) is expressed by the following single linear equation with its corresponding correlation coefficients:

$AR = 9.448 - (0.401 * CW)$ with

$R = 0.894$, $R^2 = 0.800$, Adj. $R^2 = 0.750$, and Standard error of Estimate = 0.420

	Coefficient	**Std. Error**	**t**	**P**	**Standard Coefficient**
Constant	9.448	1.105	8.552	0.001	
CW	-0.401	0.100	-3.996	0.016	-0.894
Analysis of Variance:					
	DF	**SS**	**MS**	**F**	**P**
Regression	1	2.822	2.822	15.971	0.016
Residual	4	0.707	0.177		
Total	5	3.528	0.706		

The details of the statistical out-put indicates that the relationship developed between Carriageway width and AR is significant ($p<0.05$) with a relatively high R^2 value.

Many problems in engineering require to decide whether to accept or reject a statement about some correlations [22]. A number of techniques can be used to judge the adequacy of a regression model, some of which are standard error (ε), R-squared value (R^2), R-adjusted and the p-value.

The above Correlation and Regression analyses are summarized and presented in Table 4.1 as shown below:

Table 4.1: Summary of Simple Linear Regression Analysis Models

Model Name	R	R^2	Adj R^2	Coeff.t	Constant	Std. error of estimate	St.d error (P-value)	Sig. order based on R^2 & p
Model 1	-0.951	0.904	0.872	-0.0119	6.0330	0.369	<0.05	1
Model 2	0.796	0.634	0.543	0.577	4.092	1.135	>0.05	3
Model 3	0.583	0.340	0.175	0.0000306	0.313	0.016	>0.05	5
Model 4	0.775	0.601	0.502	0.178	3.868	0.607	>0.05	4
Model 5	-0.894	0.800	0.750	-0.401	9.448	0.420	<0.05	2

From the above developed single linear regression models, based on the significant standard error (p-value) and coefficient of determination (R^2), it was noted that the Accident Rate value correlates relatively high with Radius of Curve and Carriageway Width which is an indication for these variables to form the multiple regression variables that could yield a better correlation result. While the remaining parameters showed a relatively low to moderate relationship with Accident Rate.

For further reference, the detail of the above Models is shown in Appendix A.

4.6.2 Multiple Linear Regression Analysis

During the multiple linear regression analysis, after combination of predictors the following results were obtained for the selected variables and significant relationships are presented hereunder:

Model A: Correlation of Accident Rate with Radius, Grade, Super elevation, and Carriageway Width.

The resulting regression analysis after correlating Traffic Accident with Radius, Grade, Super elevation, and Carriageway Width is expressed by the following multiple regression equation with its corresponding correlation coefficients.

$AR = 19.384 - (0.00553 * R) - (0.834 * CW) + (1.494 * e_{min}) - (0.353 * e_{max}) + (0.704 * G_{min}) - (1.197 * G_{max})$

$R = 0.976$ $R^2 = 0.952$ Adj. $R^2 = 0.926$ and Standard Error of Estimate = 0.427.

The details of the statistical out-put of the above Model indicates that the relationship developed between Traffic Accident with Radius, Grade, Super elevation, and Carriageway Width is significant with all independent variables appear to contribute to predicting Accident ($P<0.05$). Besides, the R^2 value of Model A is the best of all the above stated models. Furthermore, the detail of Model A is shown in Appendix A.

	Coefficient	Std. Error	t	P	VIF
Constant	19.384	2.650	7.313	<0.001	
R	-0.00553	0.00172	-3.213	0.008	8.559
CW	-0.834	0.137	-6.099	<0.001	4.286
e_{min}	1.494	0.177	8.457	<0.001	2.955
e_{max}	-0.353	0.0593	-5.949	<0.001	1.792
G_{min}	0.704	0.139	5.076	<0.001	13.923
G_{max}	-1.197	0.213	-5.626	<0.001	29.150

Table 4.2: Summary of Single and Multiple Regression Analysis Models

Regression Type	Model Name	R	R^2	Adj R^2	Std. error (P-value)	Sig.ce order based on R^2 & p
Single Linear Regression Model	Model 1	-0.951	0.904	0.872	<0.05	2
	Model 2	0.796	0.634	0.543	>0.05	4
	Model 3	0.583	0.34	0.175	>0.05	6
	Model 4	0.775	0.601	0.502	>0.05	5
	Model 5	-0.894	0.800	0.750	<0.05	3
Multiple Reg.n Model	Model A	0.976	0.952	0.926	<0.05	1

Pairs of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For the pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Among these developed models from single and multiple linear regression analysis techniques, all parameters of Model 1 and Model 2, show maximum relation with accident and hence adopted. Therefore, from the results of above analysis models, a combination of road geometric constituents correlates better with traffic accidents than individual geometric characteristics.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Road geometric design elements are effective factors on Traffic Accident. As the relationships between traffic accident and road geometric design elements are considered some relationships can be seen intuitively at a first approach. However, the main objective is to determine the level of these relationships quantitatively. Although the relationships generally show the same tendency, their levels vary according to each geometric characteristic conditions.

In this study, made on a trunk road segment from Gohatsion to Dejen, it has been found that elements related with horizontal alignment (Radius of Curve and Carriageway Width) are strongly related with traffic accident than the influence of other parameters. This situation can be described by the fact that the subject road is found on a difficult topographic alignment where the effect of elements related with vertical and horizontal geometry is expected to increase. A post-accident analysis approach was adopted in this study based on accident and road design data.

The location of accidents selected for the case study were only those provided by the police. The traffic police recording system was not fully accurate for estimating accident locations.

Using Scatter Plot & SPSS software package techniques, correlations were done to test the relation between road geometric parameters and accident rate using Microsoft Excel. SPSS software takes data from excel file and generates tabulated reports, charts and distribution trends. For each model, regression coefficients, variances and standard error of estimates were found.

From the results of this study the following conclusions are drawn:

There is a strong statistical relationship between the radius of horizontal curve and traffic accident with $R^2 = 0.904$ and standard error of ($p<0.05$). The accident rate and severity of injuries increase with decreasing radius of curve as seen from the resulting linear regression analysis equation with its corresponding correlation coefficients:

$AR = 6.033 - (0.0119 * R)$, with $R^2 = 0.904$ and Adj. $R^2 = 0.872$.

Accidents cluster at curves with radii less than 100 m.

The statistical relationship between Carriageway Width and Accident Rate is moderate with $R^2 = 0.80$ and standard error of ($p<0.05$). Carriageway width ≤ 8 m has highest accident rate.

Super elevations of 3.5−4.5% results the lowest accident value. Accident rate increases with road sections deviating from this range.

The accident rate has a relatively low relationship with grade having insignificant standard error value of ($p>0.05$). Accident rate is low in the lowest percentage of grade and increases with increasing in percentage of downgrade.

The risk of road traffic accident also varies with respect to AADT of the road.

Thus, among the single linear regression analysis the correlation between Accident Rate and Radius of Horizontal Curve has resulted the highest value with the following relationships:

$AR = 6.033 - (0.0119 * R)$ with, $R = 0.951$, $R^2 = 0.904$, Adj. $R^2 = 0.872$ and ($P < 0.05$).

Relatively an improved correlation than the single regression is obtained when multiple regression is used as given in the following relationship:

$AR = 19.384 - (0.00553 * R) - (0.834 * CW) + (1.494 * e_{min}) - (0.353 * e_{max}) + (0.704 * G_{min}) - (1.197 * G_{max})$, with $R = 0.976$, $R^2 = 0.952$, and Adj. $R^2 = 0.926$.

In light of the above, a combination of road geometric components correlates better with rate of traffic accidents than individual parameters.

Generally:

- With increase in horizontal curve, the accident rate decreases.
- With increase in Carriageway width, the accident rate decreases.
- With increase in vertical grade, the accident rate increases.
- With increase in super elevation, the accident rate increases.
- With increase in AADT the traffic accident also increases.

Buses/ Mini Buses are involved in a maximum no of accidents on the case study area.

Heavy vehicles like trucks are also involved in a high no of accidents. Fatalities caused by Buses/Mini Buses and Goods Vehicles were representing 48.51% and 15.18% respectively followed by Pickups (12,21%), Others (6.93%), Cars and Station Wagon (6.27%), and Motor Cycle and Cycle (2.31%). Road safety awareness should be raised among road users.

Injuries are the dominating types of accidents constituting the highest variations in accident's degree of severity (47.1%) followed by PDO (28.9%) and Fatal (24%) crashes.

5.2. Recommendations

The exposure encountered in trying to conduct the current research has revealed an area where further efforts may be proved in the future. Based on deep understanding of the main causes of accidents (particularly in relation to road geometric components), low cost engineering measures were proposed. On the existing situation or identified causes, improvement was suggested. In general, the following recommendations should be implemented:

1. Further investigation is required to study the correlation between road surface data (unevenness, wheel rut and road pavement condition) and traffic accident using integrated software applications.
2. Reporting of all types of accidents in official road accident statistics should be complete.
3. Advanced warning signs and regulatory speed posts should be placed as per the road layout.
4. Solid yellow marking lines should be provided for all edges of the pavement to delineate the edge of the road so that it is visible for drivers to decide on.
5. Provide rumble strips along the roadway to alert drivers about possible dangers by causing a tactile vibration and audible rumbling, which is found to be more effective for alerting drivers on steep gradient.
6. Restrict night driving by distinguishing vesicles that causes heavy accident severities.
7. Provide safety barriers at adverse road sections to increase the psychological confidence of both drivers and passengers.
8. Apply curve widening on adverse horizontal curved sections for safe and smooth turning position of long vehicles.
9. Avoid difficult approach roadway alignment to the Bridges.
10. Reduce the speed of water, oil and mixer trucks passing through difficult horizontal curves.

This road segment lacks sufficient surface and base that can overcome the damaging effect of significant number of heavy vehicles which are now in use.

Therefore, proper planning on their maintenance and improvement is necessary to keep them efficient.

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APPENDIX A: Details of the SPSS Regression Analysis Outputs

Appendix A-1: Single Linear Regression Analysis Results

Model 1: Correlation between Accident Rate (AR) and Horizontal Radius (R)

Model Summary

Model	R	R Square	Adj. Square	Std. Error of the Estimate
1	0.951	0.904	0.872	0.369

a. Independent Variable: R

b. Dependent Variable: AR

	Coefficient	**Std. Error**	**t**	**P**	**Standard Coefficient**
Constant	6.033	0.366	16.502	<0.001	
R	-0.0119	0.00223	-5.312	0.013	-0.951

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	3.847	3.847	28.219	0.013
Residual	3	0.409	0.136		
Total	4	4.256	1.064		

Model 2: Correlation between Accident Rate (AR) and Super elevation (e).

Model Summary

Model	R	R Square	Adj. Square	Std. Error of the Estimate
2	0.796	0.634	0.543	1.135

a. Independent Variable: e

b. Dependent Variable: AR

	Coefficient	**Std. Error**	**t**	**P**	**Standard Coefficient**
Constant	4.092	1.257	3.255	0.031	
e	0.577	0.219	2.633	0.058	0.796

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	8.928	8.928	6.931	0.058
Residual	4	5.152	1.288		
Total	5	14.081	2.816		

Model 3: Correlation between Traffic Accident (TA) and AADT

Model Summary

Model	R	R Square	Adj. Square	Std. Error of the Estimate
3	0.583	0.340	0.175	0.016

a. Independent Variable: AADT

b. Dependent Variable: TA

	Coefficient	**Std. Error**	**t**	**P**	**Std. Coeff.**
Constant	0.313	0.0357	8.777	<0.001	
AADT	0.0000306	0.0000213	1.435	0.225	0.583

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**p**
Regression	1	0.000547	0.000547	2.058	0.225
Residual	4	0.00106	0.000266		
Total	5	0.00161	0.000322		

Model 4: Correlation between Accident Rate (AR) and Vertical curve (G)

Model Summary

Model	R	R Square	Adj. Square	Std. Error of the Estimate
4	0.775	0.6014	0.502	0.607

a. Independent Variable: G

b. Dependent Variable: AR

	Coefficient	**Std. Error**	**t**	**P**	**Standard Coefficient**
Constant	3.868	0.698	5.542	0.005	
G	0.178	0.0725	2.457	0.070	0.775

Analysis of Variance:

	DF	**SS**	**MS**	**F**	**P**
Regression	1	2.221	2.221	6.035	0.070
Residual	4	1.472	0.368		
Total	5	3.694	0.739		

Model 5: Correlation between Accident Rate (AR) and Carriageway Width (CW)

Model Summary

Model	R	R Square	Adj. Square	Std. Error of the Estimate
5	0.894	0.800	0.750	0.420

a. Independent Variable: CW

b. Dependent Variable: AR

	Coefficient	Std. Error	t	P	Standard Coefficient
Constant	9.448	1.105	8.552	0.001	
CW	-0.401	0.100	-3.996	0.016	-0.894

Analysis of Variance:

	DF	SS	MS	F	P
Regression	1	2.822	2.822	15.971	0.016
Residual	4	0.707	0.177		
Total	5	3.528	0.706		

Table A-1-1: Summary of Simple Linear Regression Analysis Models

Model Name	R	R^2	Adj R^2	Coeff.t	Constant	Std. error of estimate	St.d error (P-value)	Sig. order based on R^2 & p
Model 1	-0.951	0.904	0.872	-0.0119	6.0330	0.369	<0.05	1
Model 2	0.796	0.634	0.543	0.577	4.092	1.135	>0.05	3
Model 3	0.583	0.340	0.175	0.0000306	0.313	0.016	>0.05	5
Model 4	0.775	0.601	0.502	0.178	3.868	0.607	>0.05	4
Model 5	-0.894	0.800	0.750	-0.401	9.448	0.420	<0.05	2

Appendix A-2: Multiple Linear Regression Analysis

Model A: Correlation of Accident Rate with Radius, Grade, Super elevation, and Carriageway Width.

Model Summary

Model	R	R Square	Adj. Square	Std. Error of the Estimate
A	0.976	0.952	0.926	0.427

a. Independent Variable: R, G, e, CW.

b. Dependent Variable: AR

	Coefficient	**Std. Error**	**t**	**P**	**VIF**
Constant	19.384	2.650	7.313	<0.001	
R	-0.00553	0.00172	-3.213	0.008	8.559
CW	-0.834	0.137	-6.099	<0.001	4.286
e_{min}	1.494	0.177	8.457	<0.001	2.955
e_{max}	-0.353	0.0593	-5.949	<0.001	1.792
G_{min}	0.704	0.139	5.076	<0.001	13.923
G_{max}	-1.197	0.213	-5.626	<0.001	29.150

Table A-1-2: Summary of Single and Multiple Regression Analysis Models

Regression Type	Model Name	R	R^2	Adj R^2	Std. error (P-value)	Sig.ce order based on R^2 & p
Single Linear Regression Model	Model 1	-0.951	0.904	0.872	<0.05	2
	Model 2	0.796	0.634	0.543	>0.05	4
	Model 3	0.583	0.340	0.175	>0.05	6
	Model 4	0.775	0.601	0.502	>0.05	5
	Model 5	-0.894	0.800	0.750	<0.05	3
Multiple Reg.n Model	Model A	0.976	0.952	0.926	<0.05	1

Appendix B: Details of Road Geometric, Traffic and Accident Data

Appendix B-1: Details of Road Geometric Design Data

Table B-1-1: As-built Road Drawing Index

Section	Drawing No.	Tittle
A. GENERAL	A-1/2	Drawing Index
	A-2/2	Location Map
B. ROAD	B-2/332-B-41/332	Horizontal Alignment
	B-42/332-B-81/332	Plan
	B-82/332-B-132/332	Profile
	B-135/332-B-138/332	Typical Cross Section
	B-161/332-B-164/332	Traffic Safety Work
	B-165/332-B-174/332	Cross Section
	B-199/332-B-238/332	Arrangement of Guard Post
	B-252/332-B-291/332	Arrangement of Marking
	B-292/332-B-331/332	Arrangement of Warning Sign
D.ROAD RENOVATION WORKS	D-1/13-D-7/13	Plan
	D-8/13-D-13/13	Cross Section

(Source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2009).

Table 3.1: Details of As-built Road geometric Design outputs and reported accident data at selected locations.

Sampling Location	Station	Coordinates		Curve Radius (m)	Carriageway Width (m)	Super elevation (%)		Gradient (%)		Traffic Accident
		X	Y			Min	Max	Min	Max	
At No five Road section	0+525	417032.938	1107901.141	20	12.5	3.8	8.0	5.5	8.7	4
Washa Mk. Church	5+000	417112.445	1108298.133	15	8.0	2.5	4.2	9.3	11.7	5
Snt.Gibrile church	26+970	408311.833	1117182.356	50	10.9	5.5	6.9	8.5	11.1	6
Endedir	31+970	407752.207	1119326.403	70	10.9	2.5	2.5	5.3	10.4	3
Bora Afaf	33+970	408888.202	1120540.366	30	9.0	2.5	8.0	4	9.6	3
Dembeza Snt. Mary church	35+100	408294.965	1120799.549	42	8.0	2.5	7.5	8.8	12	4
MerYesus Church	36+100	408027.777	1121010.326	180	10.6	2.5	7.5	5.2	9.1	2
Gelgele K. Mihiret Church	38+100	407065.022	1122601.664	180	10.6	2.5	3.4	3.5	7.1	4
Gypsom Quary site	39+600	406718.741	1123998.456	600	12.0	2.5	2.5	0.45	3.3	4

(Source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2009).

Appendix B-2: Details of Traffic Accident Data.

Table B-2-1: number of accidents observed through various types of vehicles from 2002 to 2007.

Type of Vehicles Involved	Traffic Accidents Occurred During the Analysis Period							
	2002	2003	2004	2005	2006	2007	Sum	%
Car	2	4	1	3	6	3	19	6.30
Goods Vehicle	9	8	5	8	9	7	46	15.18
Bus/Mini Bus	26	28	15	28	20	30	147	48.51
Motor	2	1	1	2		1	7	2.30
Pickup	8	10	4	7	2	6	37	12.21
Cycle	1	2		1		3	7	2.30
Station Wagon	1	4	2	2	3	7	19	6.30
Others	2	1	2	10	5	1	21	6.93
Total	51	58	30	61	45	58	303	100

Source: Police Commission, Gohatsion and Dejen Woreda Road Traffic Accident Statistics Office.

Table B-2-2: Annual Variation of accidents by their degree of severity

Year (E.C)	Total No. of accidents	fatal	Injuries	PDO
2002	51	33	17	26
2003	58	25	93	32
2004	30	9	31	26
2005	61	17	20	31
2006	45	14	19	29
2007	58	60	126	44
Total	303	156	306	188

(Source: Police Commission, Gohatsion and Dejen Woreda Road Traffic Accident Statistics Office).

Appendix B-3: Details of Road Traffic Data.

Table B-3-1: Vehicle Classification by class

Vehicle Code	Type of Vehicle	Description
1	Small Car	Passenger cars, minibuses (up to 24-passenger seats),Taxis, Pick-ups, and Land Cruisers, Land Rovers, etc.
2	Bus	Medium and large size Buses above 24 passenger seats
3	Medium Truck	Small and medium sized trucks including tankers up to 7 tons load
4	Heavy Truck	Trucks above 7 tons load
5	Articulated Truck	Trucks with trailer or semi-trailer and Tanker trailers

(Source: Road Asset Management. and Contract Implementation Coordination Directorate).

Table B-3-2: Annual Average Daily Traffic by Road Section and Vehicle Kilometer of Travel

Year	**VEHICLES CATEGORY**					**VEHICLE KILOMETER OF TRAVEL**				
	Cars & Land R.	**Bus**	**Truck**	**Trucks & Trailer**	**Total**	**Cars & Land R.**	**Buses**	**Trucks**	**Trucks & Trailer**	**Total**
2002	182	320	446	139	1,087	7,462	13,120	18,286	5,699	44,567
2003	223	393	599	189	1,404	9,143	16,113	24,559	7,749	57,564
2004	263	464	740	230	1,697	10,783	19,024	30,340	9,430	69,577
2005	272	492	784	251	1,799	11,151	20,172	32,144	10,291	73,759
2006	286	472	842	266	1,866	11,726	19,352	34,522	10,906	76,506
2007	325	519	888	288	2,020	13,325	21,279	36,408	11,808	82,820
						63,590	109,060	176,259	55,883	404,793

Source: "Traffic Survey and Safety Measures Report for Gohatsion–Dejen Road Project, Detailed Engineering Design, Tender Document Preparation and Construction (2014)'').

Table B-3-3: Traffic data of the present study

Year	Cars	Land Rover	Small Buses	Large Buses	Small Truck	Medium Trucks	Heavy Trucks	Trucks & Trailers	Total
2002	39	143	225	95	173	156	117	139	1,087
2003	49	174	277	116	201	222	176	189	1,404
2004	58	205	327	137	229	285	226	230	1,697
2005	61	211	350	142	234	305	245	251	1,799
2006	66	220	312	160	251	310	281	266	1,866
2007	69	256	319	200	263	322	303	288	2,020

(Source: "Traffic Survey and Safety Measures Report for Gohatsion–Dejen Road Project, Detailed Engineering Design, Tender Document Preparation and Construction (2014)'').

Appendix C: Details of Maps, Diagrams, and Charts

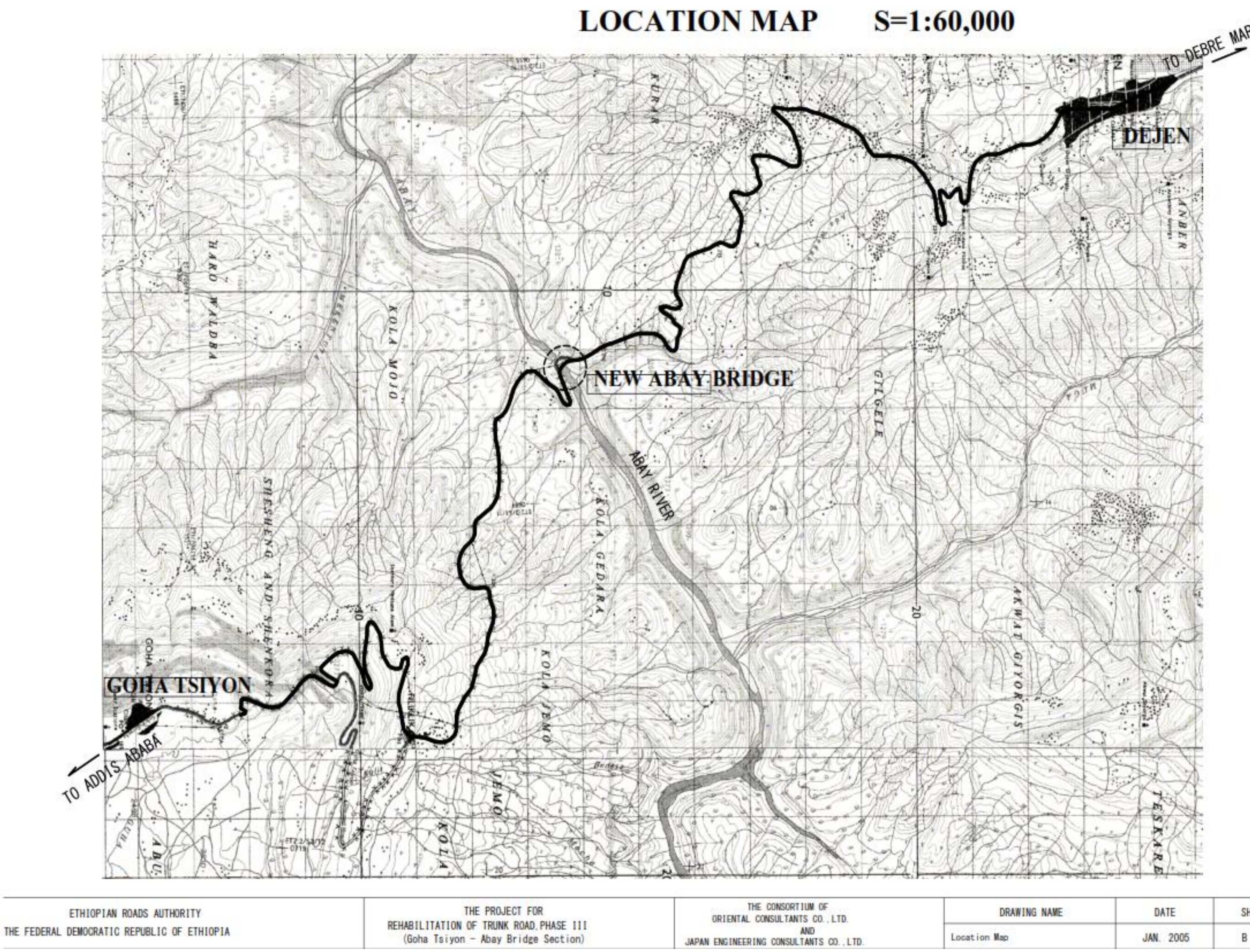


Figure C-1: Location map of the study area (source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2008).

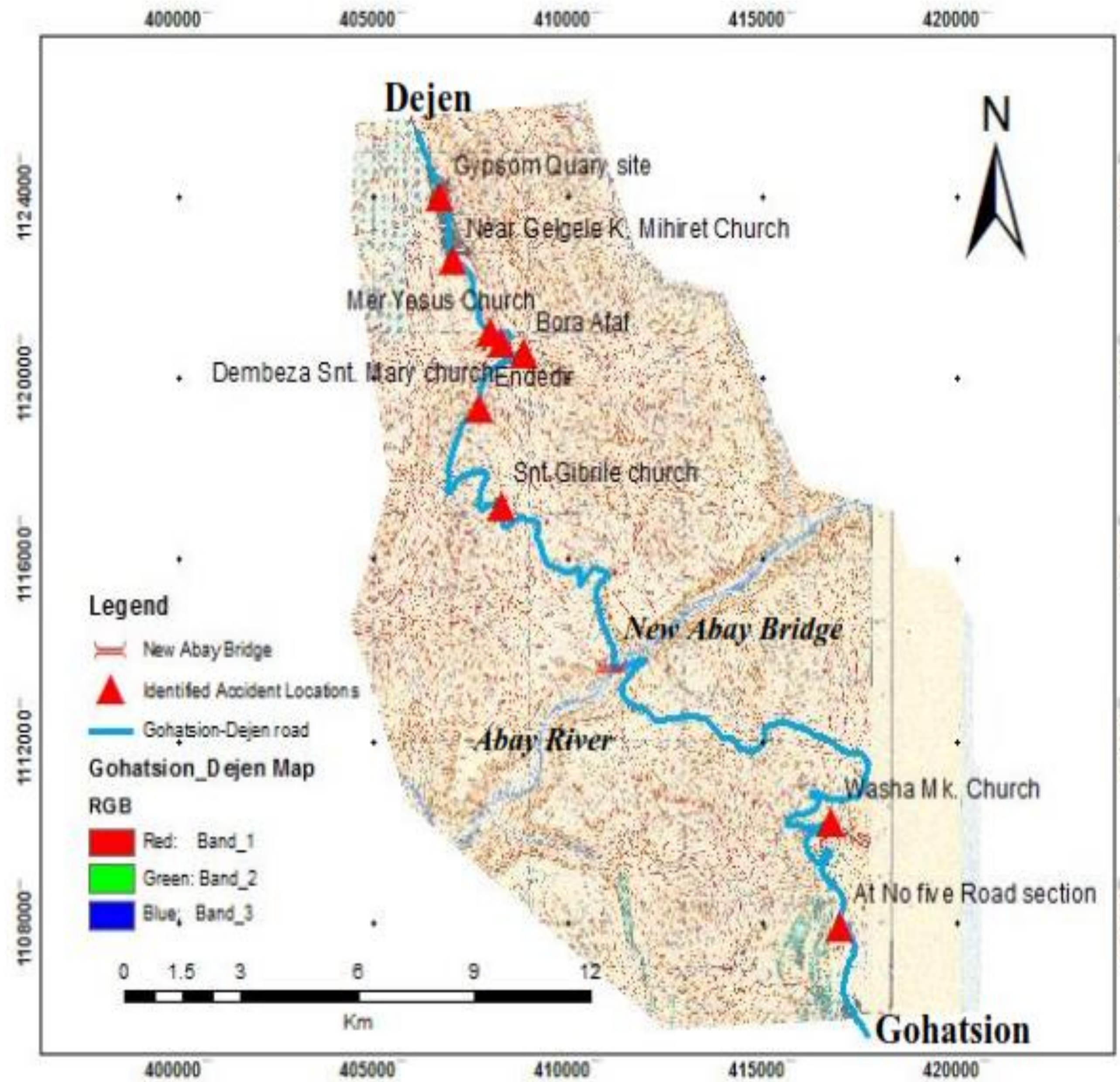
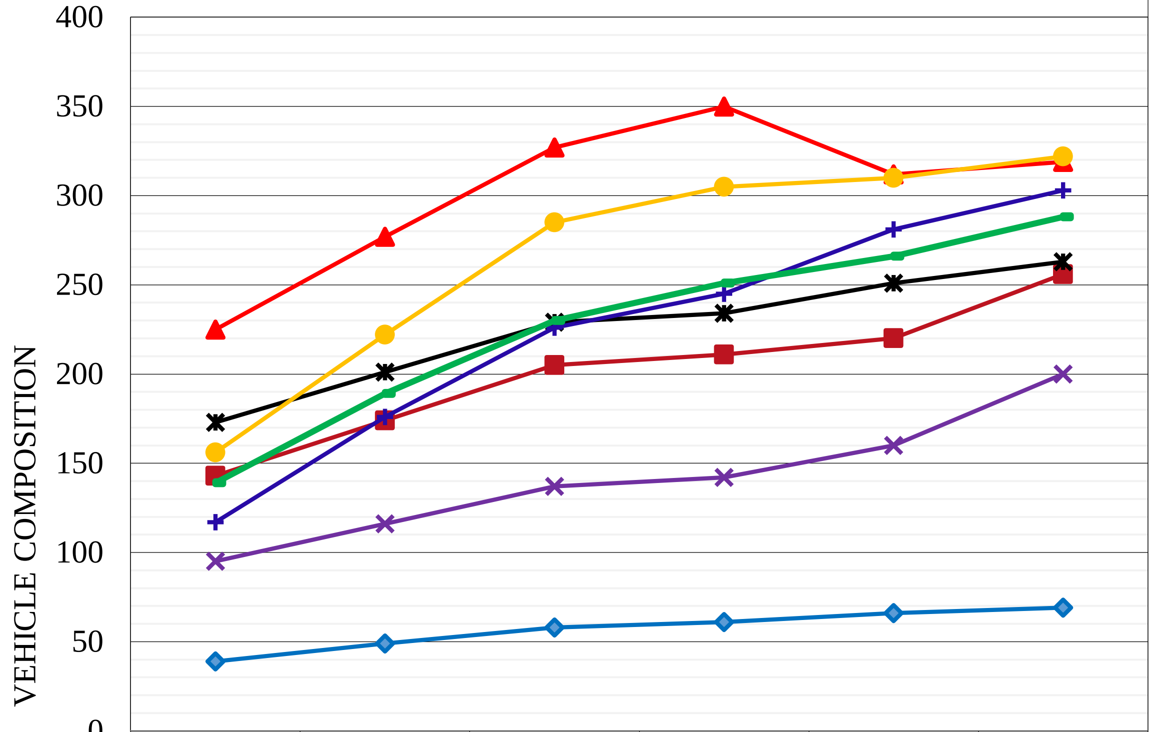


Figure C-2: Identified accident locations along the case study area (Source: Arc GIS 10 Result).



	2002	2003	2004	2005	2006	2007
Cars	39	49	58	61	66	69
Land Rover	143	174	205	211	220	256
Small Buses	225	277	327	350	312	319
Large Buses	95	116	137	142	160	200
Small Truck	173	201	229	234	251	263
Medium Trucks	156	222	285	305	310	322
Heavy Trucks	117	176	226	245	281	303
Trucks & Trailers	139	189	230	251	266	288

Figure C-3: Distribution of Annual Average Daily Traffic over the analysis period

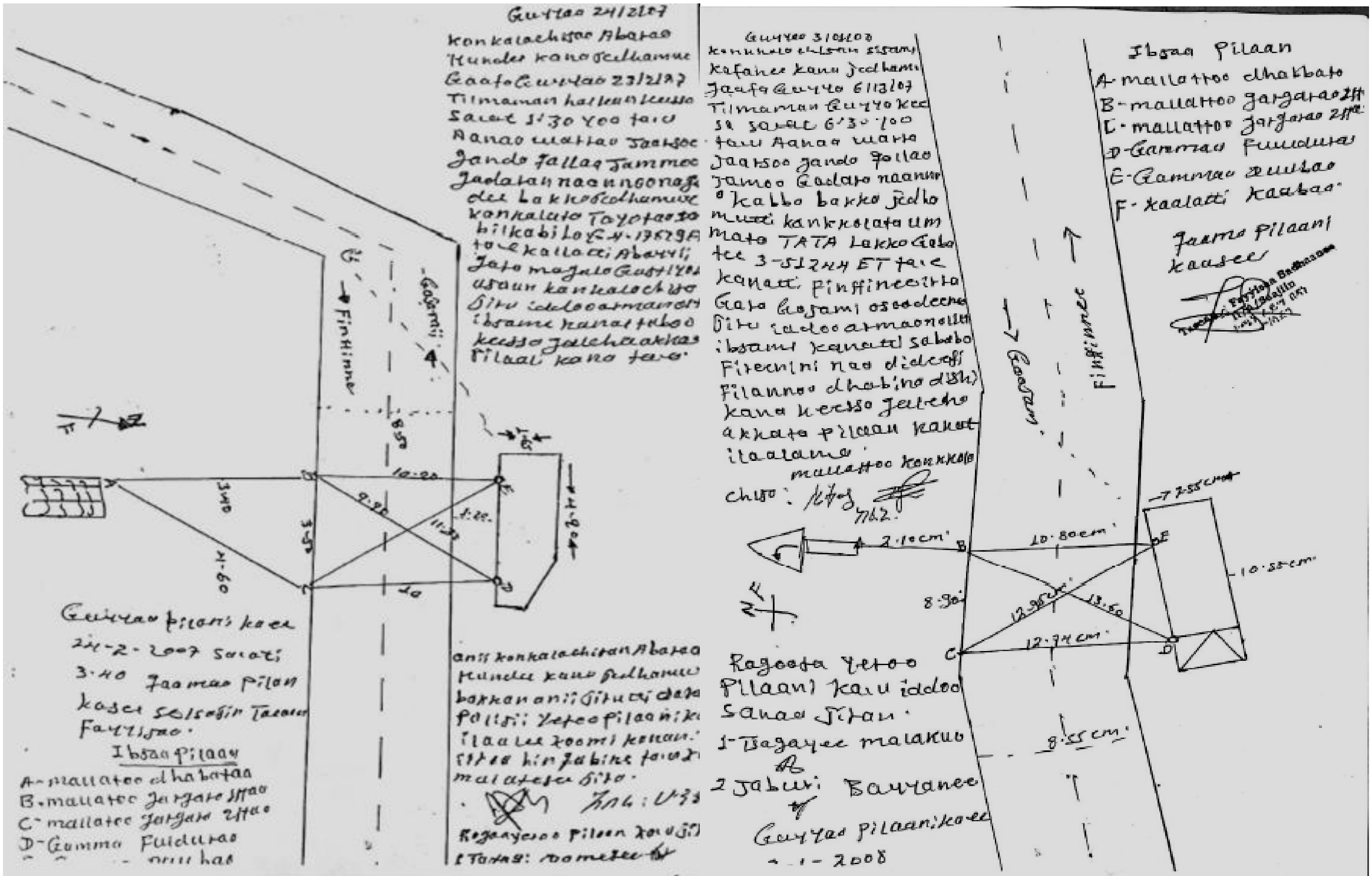


Figure C-4: Accident Scene Diagrams at selected locations in Worejarso Woreda Gadera Kebele

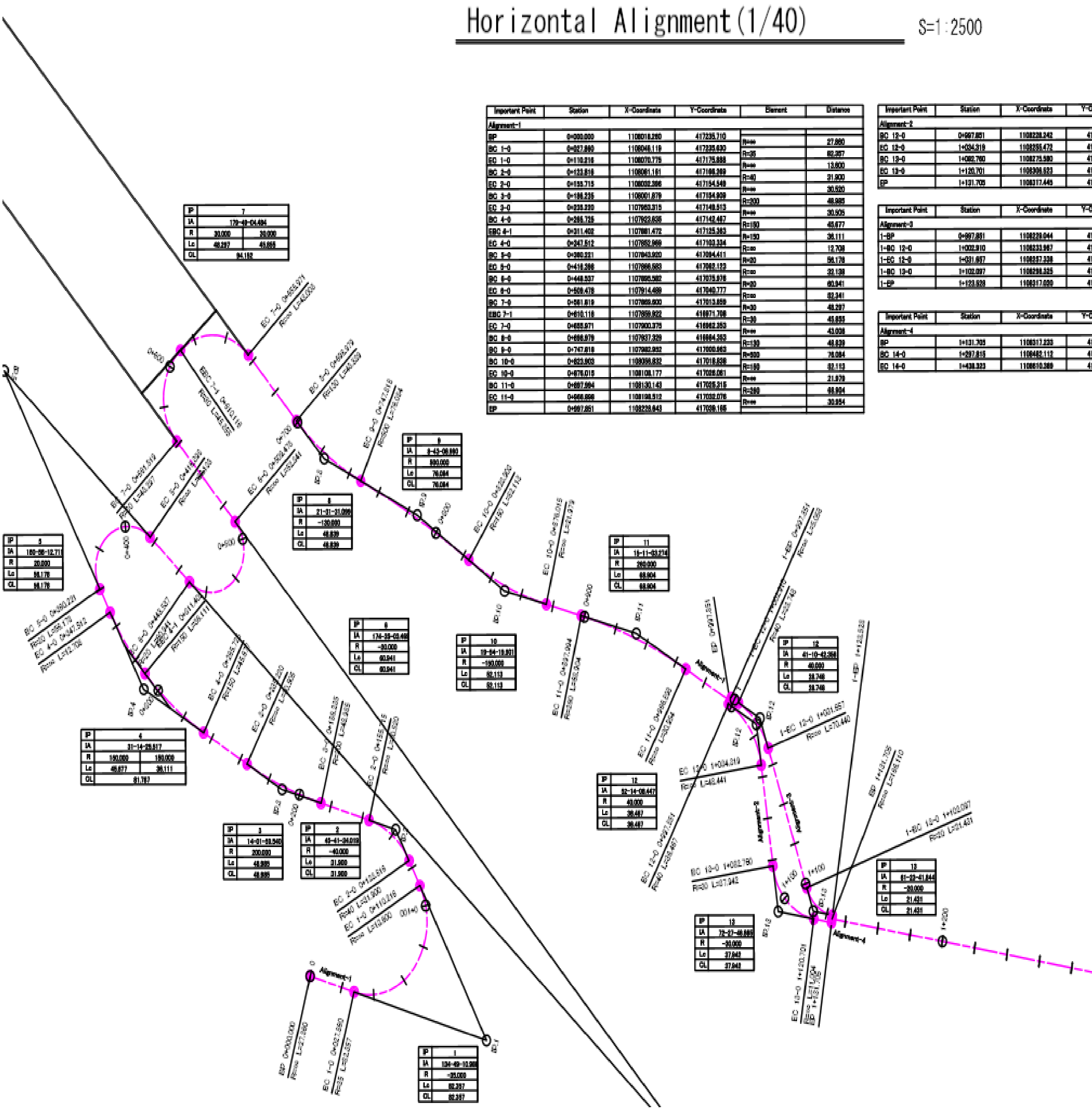


Figure C-5: As-Built horizontal Alignment from Gohatsion to Abay Bridge Section. (Source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2009).

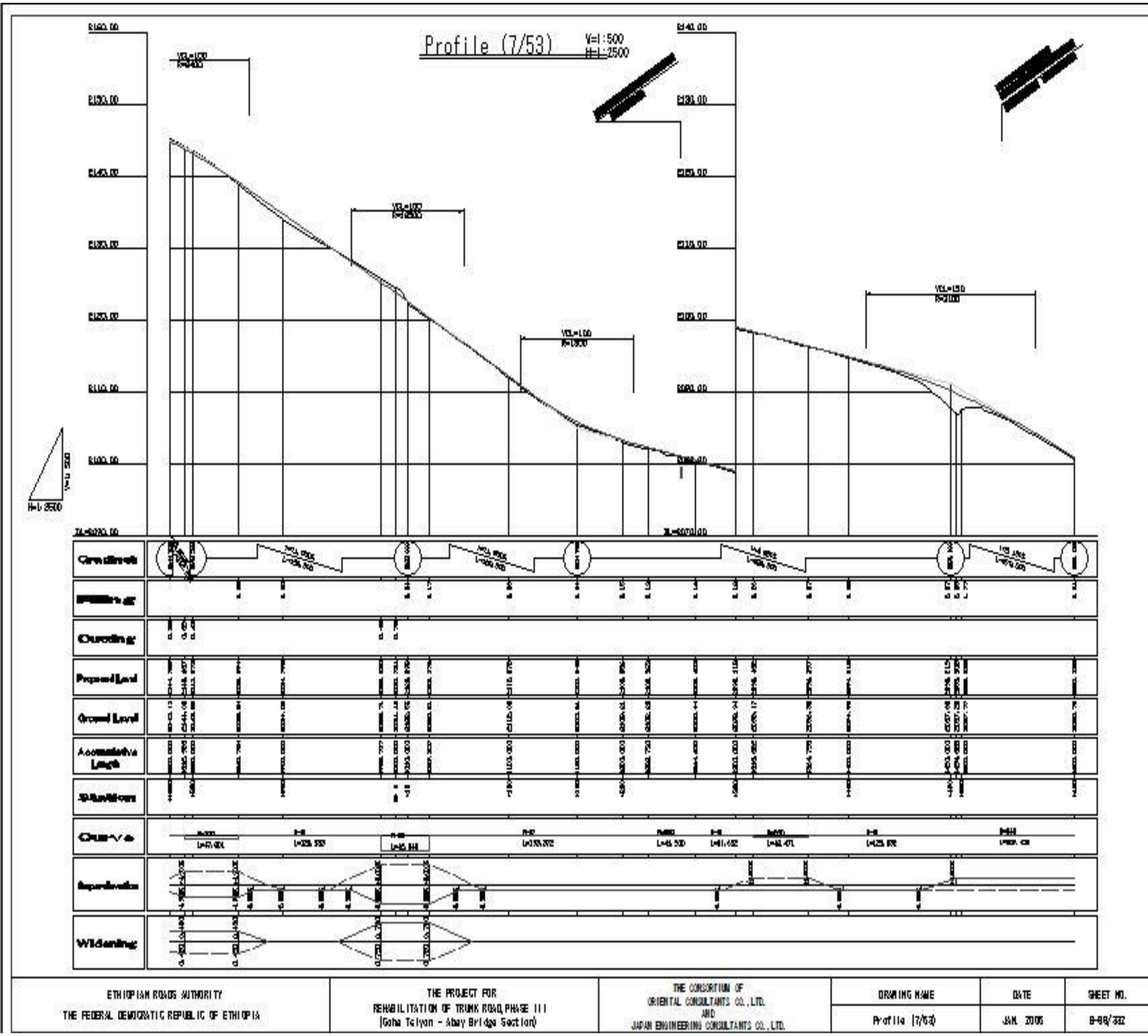


Figure C-6 Sample Road Cross section profile (Source: Project Completion Report for Rehabilitation of Trunk Road, Phase III (Gohatsion - Dejen Section), 2009).