JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
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EFFECTS OF ROUTE AND GEOMETRIC DESIGN DEFICIENCIES ON THE ROAD USERS: A CASE STUDY ON ADDIS ABABA - JIMMA HIGHWAY

A Thesis Proposal Submitted to School of Graduate Studies in Partial Fulfillment of the Requirement for Degree of Masters of Science in Highway Engineering

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As members of the examining board of the final MSc. open defense, we certify that we have read and evaluated the thesis prepared by Wondimu Biftu entitled: **“Effects of Route and Geometric Design Deficiencies on the Road Users: A Case study on Addis Ababa-Jimma Highway”**, recommended that it have been accepted as fulfilling the thesis requirement for the degree of masters of science in Highway Engineering.

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ACRONYMS

AADT = Average Annual Daily Traffic

AASHTO = American Association of State Highway and Transportation Officials

ADB = African Development Bank

BADEA = Bank of Arab for Economic Development in Africa

DS = Design Standard

ECX = Ethiopian Commodity Exchange

EDRI = Ethiopian Development Research Institute

EFY = Ethiopian Fiscal Year

ERA = Ethiopian Roads Authority

ETCA = Ethiopian Transport Construction Authority

FHWA = Federal Highway Administration

GDM = Geometric Design Manual

GIS = Geographic Information System

LHS = Left Hand Side

NDF = Nordic Development Fund

OFID = OPEC Fund for International Development

PA = Peasant Association

PDO = Property Damages Only

PI = Point of Intersection

RAI = Rural Access Index

RHS = Right Hand Side

RRA = Rural Roads Authorities

RROW = Road Right Of Way

RSA = Road Safety Audit

RSDP = Road Sector Development Program

SRTM = Shuttle Radar Topographic Mission

TCDE = Transport Construction Design Enterprise

VPD = Vehicles Per Day

ABSTRACT

More proactively good road design and well-developed traffic management measures produce roads which are safer and which are less likely to develop as black spots. However, Addis Ababa - Jimma road, especially Gibe Bridge to Deneba road segment, among the roads and trails built and improved during the five years Italian occupation, at that time, considered to represent the optimum route as it was, today the road lacked most of the modern highway location, geometric design and construction features desirable for present day traffic volume, large size, heavy weight and high-speed traffic. These road segment, consists of 6m and 6.5m wide narrower road section and several narrower bridges are located in sharp horizontal curves, the curve length accounts 50.9% of the route, the existence of 56.24% of curves radii below 40m including all of the seven switch-back curves and 57.8% of the vertical alignment fall into 5%-10% grade.

To alleviate these deficiencies, ERA conducted rehabilitation measures without major changes, except re-alignment of the road from station km 268+954 to 302+170 and the widening of existing 6m carriageway width to 6.5m to 7m in most parts of the route. However, still there is a traffic crash occurrence, particularly on Gibe bridge to Deneba road segment which has causing a significant human life loss with traffic crash rate of 1.57 and huge estimated property damages cost of 179,343.49 ETB/Km in five years of 2003-2007 E.F.Y for the road users as well as highway structures re-location/re-placement costs of ETB 41,673,094.63 in four years of 2012-2015 G.C for the government are noticeable on the route mostly due to the initial geometric design deficiencies of the road.

In order to address these problems, this research was done by reviewing traffic accident data of 11 Woredas and 3 City Administrations Police Offices, As-built Design Drawings, Tender and Final Project Reports of the existing Addis-Jimma Road Rehabilitation Project, traffic count data of the past 5 years and highway drainage crossing structures relocation cost of the past 4 years. The current ERA and AASHTO geometric design manuals as well as previous studies were also reviewed having access to the information in other countries in order to understand the existing knowledge and experiences.

Comparative analysis was applied to characterize the collected data to investigate the deficiencies of geometric design attributes and highway drainage crossing structures relocation cost on the route by dividing the route into three segments, to identify the black-spot road segment by crash rate and property damages cost by dividing the route into four road segments. GIS based least cost route selection analysis was conducted by giving influence factor of 60% for slope and 40% for stream order. Finally, short-term (low-cost) and long-term (high-cost) engineering interventions including GIS based most appropriate route corridor selection (by the least cost path method using computer application of ArcGIS version 10 software) which can minimizes road traffic accident, travel time cost, vehicle operation and maintenance cost and highway structure maintenance cost has been recommended.

Key Words: Alleviate, attributes, Corridor, Departure, Deficiencies and Interventions.

CHAPTER ONE
INTRODUCTION

1.1. Background of The Study Area

Addis Ababa-Jimma road is located in South-west direction from the country's capital and found along the Trunk Road Addis – Metu, numbered as A-5 by Ethiopian Roads Authority (ERA), comprises of about 342 Km, which were among the roads built during the five years Italian occupation (ERA Geometric Design Manual, 2002). Since this road was damaged due to lack of adequate maintenance and long service of life, the Ethiopian Roads Authority was proposed a rehabilitation measure named as Addis Ababa – Jimma Road Rehabilitation Project.

A feasibility study for a project to rehabilitate the existing Italian road between Addis Ababa and Jimma was completed by Planco Consulting GmbH and DIWI Consult International GmbH in February 1995. Following this, detailed engineering designs of existing road were prepared by Studio Pietrangeli (SP) of Rome between May 1995 and September 1997 while the Gilgel Gibe Realignment section was designed by Transport Construction Design Enterprise (TCDE) of Addis Ababa. The construction work was carried out between 1999 to 2008 G.C by the joint venture of Dragados / J & P (Hellas) S.A. Joint Venture and the supervision work was conducted by a joint venture of DIWI Consult International GmbH (Germany) and TYPSA Tecnica Y Proyectos SA (Spain).

The Gilgel-gibe Dam has been constructed a short distance to the north of km 268. The reservoir was inundated a section of the existing Italian Addis-Jimma road and this necessitated the construction of a new road, commencing at station km 268+954 and re-joining the existing road at km 302+284. The length of this section is 33.33 km and is referred to as the "Realignment Section". The existing road rehabilitated was 308.241 km long and thus total length of the road covered by the Project was 341.541 km.

The road is a two-lane two-way highway with a relatively highly trafficked route next to Addis-Adama outlet (from the five outlet road of the capital city of the country) and it is also the only means of land transport to connect south-western parts of Ethiopia to Addis Ababa. Due to these facts, the road is considered as the most vital route in terms of economic and traffic volume.

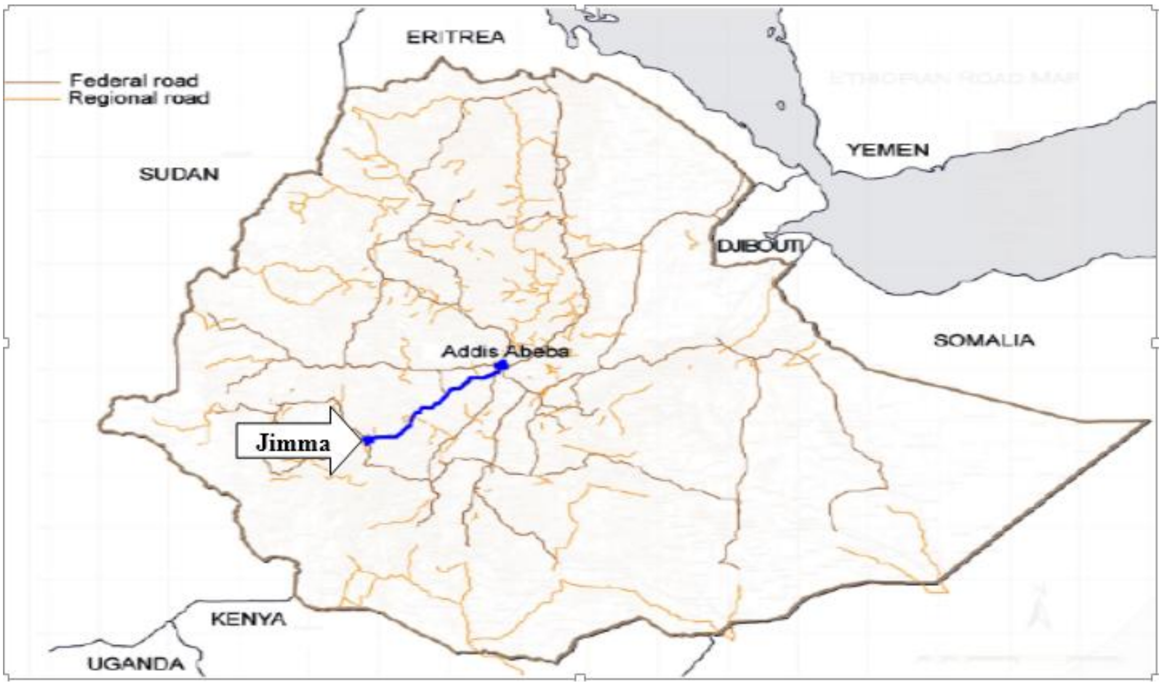


Figure 1.1: Map of Addis Ababa-Jimma Highway

1.2. Statement of the Problem

Among those roads, Addis Ababa to Jimma Road, especially the road section found in Gibe Gorge comprised what, at that time, was considered to represent the optimum route and most certainly consisted of very significant volumes of rock cut and fill to construct a platform that was adequate for the intended road width of 6m (Addis Ababa to Jimma Road Rehabilitation Project Final Report, 2010). However, today the road lacked most of the modern highway location, geometric design and construction features desirable for present day traffic volume, large size, heavy weight and high-speed traffic (ERA, History of Road Building in Ethiopia Document). In order to alleviate these problems, the Ethiopian Roads Authority (ERA) was conducted rehabilitation measures along the existing Addis Ababa to Jimma highway in 1999-2008 G.C.

However, there were no major changes of route (except the re-aligned road from Station 268+954 to 302+170) and geometric design features (except widening of the existing 6m carriageway width to 6.5m-7m). Despite this, the road segment in and approaches to Gibe valley (from stations km 185+700 to km 266+000) consists of very sharp horizontal curves including about seven Switch-back curves (curve radii less than 20m, with the minimum of radii 13.75m) and higher gradients up to 9.65% which are departure from current ERA standards for Ethiopian paved roads of DS1 to DS4 and many narrow bridges are located in sharp horizontal curves. Because of this, the road segment from

Gibe Bridge to Deneba is still known as the challenging road segment for many drivers, especially for those are new for the road segment.

As a matter of fact, there have been occurrence of traffic accidents along the road segment which resulted in loss of human life and property damages to the road users and noticeable highway structures re-location costs to the government. It is for this reason that this research study has conducted to address the acute road user's problems through the detail analysis of input data, conclusions and recommendations of short-term and long-term interventions (including new route selection by the least cost path method based on ArcGIS 10 computer application software) on the black spot road segment and particular areas through road safety audit of geometric design features along Addis Ababa-Jimma road. Besides, this thesis can be used as an initiation for road safety audit team professionals of the concerned roads and transport agencies and researchers for further analysis of road problems along the route.

1.3. Research Objectives

1.3.1. General Objective

To investigate effects of route and geometric design deficiencies on the road users on existing Addis Ababa to Jimma highway.

1.3.2. Specific Objectives

- To identify deficiencies of highway route location and geometric design features on the existing road;
- To identify the critical traffic accident road section and particular black-spot areas in relation with route and geometric design deficiencies on the existing highway route;
- To evaluate highway structures re-location/re-placement costs in relation with route and geometric design deficiencies on the existing highway route;
- To analyze and recommend possible short-term (low cost) and long-term (high cost) engineering interventions (measures) including options, selection of the most appropriate route corridor by the least cost path method analysis using ArcGIS version 10 computer application software.

1.4. Scope of the Research

The scope of the study was limited to Addis Ababa - Jimma road, starting from station Km 10+670 (roundabout junction with the Addis Ababa ring road, near Ayer-Tena) to Jimma station km 352+241 (outside ECX compound at Jimma) with a total length of 341.571 kilometers. Besides, the study was focused on its direction in identifying black-spot road section and particular areas along the route and recommendations of possible short-term and long term countermeasures.

1.5. Organization of the Research

The research paper is organized into six chapters. Chapter one is an introduction to the paper and contains background of the study area, statement of the problem, research objectives, scope of the research, organization of the research and limitations of the research. Chapter two presents review of the literature on overview of the past and recent road network expansions and sector policies, the current traffic accident situations and reasons for high number of road traffic crashes in Ethiopia and studies on highway design philosophy and road safety audit practices are reviewed and discussed in this chapter.

In chapter four, details of study area, research design, study variables, data source and research populations, methods of data processing and analysis used to conduct the research work have been stipulated. In chapter five, analysis of road geometric design attributes, characterizations of road traffic crashes, identification of causes of traffic accidents and black-spot road sections and particular areas that is supported by site visit, in-depth investigation and the results were discussed. Finally, based on the analysis and findings, the research comes up with a general conclusions and recommendations of engineering measures have been proposed for implementation which is in chapter six.

1.6. Limitations of the Study

During the preparation of this paper, the writer faced many challenges such as in some Woredas, there were inadequacy in the availability of road traffic accident data as the required quality and suitability for the preparation of research paper. Since many traffic accident data do not recorded all information desirable for identifying the real cause of traffic accident and black-spot areas, often because the traffic police collecting the data focus on blame in order to enable prosecution and compensation issues resolved.

As an example, during the way of traffic accident data collection in Woredas and City Administrations found along Addis Ababa-Jimma Road, name of traffic crash areas were recorded by Kebele/Peasant Association (PA) name, Woreda name , even in region name and non-recorded (nil) instead of recording by post (km), special/particular name of traffic accidents areas.

On the one hand, in some two Woredas and one City Administrations, the traffic accident data before January 2005 E.C were recorded by Woredas and Cities Road Transport Offices for some years while after January 2005 E.C were recorded by Woredas and Cities Police Offices. During this transition period, because of workforce and work divisions transfer from one office to another office, traffic accident data of some months upto one year were lost or otherwise not recorded responsibly. On the other hand, the field work was time consuming since Traffic Police Officers had many tasks and were usually out of their offices, it was difficult to get them.

In addition to poor traffic data collection, recording and handling trends of Police Offices found along the route, the problems stated above were some of a big challenges encountered the researcher during data collection process. These conditions were hindered the writer of this research paper to apply scientific formulas in the identification and prioritization of black spot areas as the required level. Hence, to overcome these stated problems, the identification of black-spot areas were identified by rewriting and re-arranging traffic accident data recorded on daily criminal record (CR) of police, oral interview of the drivers using the route for repeated period of time, by asking and referring notes of most repeated traffic crash areas from traffic polices working for a long period of time on Woredas and Zonal Traffic Police Offices.

CHAPTER TWO

REVIEW OF THE LITERATURE

2.1. Overview of Past Road Network and Sector Policies in Ethiopia

The history of the Ethiopian road network goes back to the very beginning of the Ethiopian state. This origin can be related to the reign of Emperor Tewodros (1855-1868 G.C), who was also the pioneer of road construction in Ethiopia. Associated with his intention to expand the (northern highland) empire, he recognized the strategic and political importance of roads. Consequently, a relatively small-scale road network was constructed and enabled the Emperor to rapidly move his troops to the centers of rebellion in the conquered areas.

In the late 19th century, the city of Addis Ababa, founded in 1887, replaced the northern highland as the geographical center of political power uses a center-periphery concept and points to the importance of overcoming physical distance for communication within the empire. However, Tewodros' successors also paid great attention to road construction, especially Menelik II (1889-1913 G.C) and his province governors.

During the reign of Haile Selassie (1930-1936 G.C), the capital-centered (Addis Ababa) road network was intensified and modernized for economic and political reasons. On the one hand, the emerging motor traffic since the advent of the motorcar in Ethiopia in 1907 G.C had increased the demand for roads within the capital. On the other hand, the global economic crises and world depression in 1929-1933 G.C forced the reign to improve the capital's road communication with the provinces. However, despite the intention to expand the country's road network, it remained poorly developed until the Italian occupation.

During the Italian occupation (1936-1941 G.C.), considerable efforts were undertaken with respect to road infrastructure, and the Ethiopian road network expanded from about 1,040 km in 1930 G.C to about 6,400 km in 1941 G.C. Initially, road construction started as a preparation for war in the early Italo-Ethiopian conflict. While these initial roads had been constructed where the Italian's penetrated the territory, i.e. Eritrea, the activities continued inside Ethiopia after the invasion in 1936 G.C. The road construction activities followed in the footsteps of the invading forces so that paved roads would allow easier and swifter passage of troops and supplies. From a strategic point of view, the priority was given to roads linking major towns, but also to those linking the 'colony' with the outside world. Attention was paid to quantity rather than quality, and several new roads were constructed and pre-war roads maintained, upgraded or elongated.

Several political and economic arguments can be found for the improvement of the transport system of the Italian colony. Most obviously, the strategic and military importance of roads led to initial construction and maintenance. The existence of a road network later helped the Italians to consolidate its rule over Ethiopia, initiate development projects and pacify unstable areas. Or, in other words, to effectively administer, economically exploit and suppress the resistance of Ethiopian patriots. In addition to the importance of roads for administering the colony, the link to the outside world also led to the expansion of the road network. As an example, Italy aimed at connecting the colony with the British Somali Port Berbera in order to become less dependent on the French-run Djibouti Railway.

On the one hand, road construction efforts were a clear sign of the Italians' attempt to transform Ethiopia into a self-sufficient export economy linked to the world market. On the other hand, given the deterioration of Franco-Italian relations, it was an obvious expression of the broader geopolitical patterns. With the Italian's involvement in World War II, road construction in Ethiopia came to a sudden end. In 1941 G.C, powerful attacks from the Anglo-Ethiopian liberation movement forced the Italians to flee and to strategically destroy parts of the road network established so far.

After the liberation of Addis Ababa, Emperor Haile Selassie re-entered the capital on 5 May 1941 G.C, while road construction and maintenance activities stagnated in the following years, they regained attention in the early 1950s G.C. Haile Selassie had sufficiently consolidated the administrative authority of the state and could now turn his attention to more economic matters. He recognized the importance of an existing road system for the economic needs of the population and the government (ERA 2004:1). Accordingly, a Highway Program (HP) was formulated in order to stimulate the expansion of market activities throughout the country. In particular, the program aimed at creating transport infrastructure, to attract foreign capital investors or to open up remote but potential and economically rich areas of agriculture, mineral resources and tourism. Attention was paid to connecting provincial capitals, other important towns, as well as the connection of Addis Ababa with the outside world through the port of Assab.

In this sense, the first Highway Program (HP I 1951-1957) focused on the inherited but deteriorated Italian road network. Several existing roads were rebuilt, reconstructed and maintained. Although the road network had initially mainly fulfilled military purposes, the roads' economic usefulness was not reduced. With the second Highway Program (HP II 1957-1965 G.C) the focus shifted toward the construction of new roads. In the following years, two further Highway Programs were formulated and increasingly opened up previously inaccessible regions of the country. Specifically, the classified road network increased from the inherited 6,400 km in 1951, to a total of 9,260 km in 1974.

In 1974 G.C, the Derg assumed power and continued with the construction of new roads on a larger scale than ever before. While the new regime initially followed the Highway Program of its predecessor, it shifted its attention to the construction of the previously neglected rural roads. The Derg regime identified the lack of access to rural areas as a serious bottleneck for agricultural development. The rural infrastructure, particularly low-cost and low-standard roads, were given increasing attention.

On the one hand, rural infrastructure was seen as a means for the achievement of socio-economic development. On the other hand, it was considered as a pre-condition for the expansion of further socio-economic infrastructure. The economic role of rural roads for the country and its population was emphasized with respect to market access in general, and the possibility for the rural population to bring their products to the market in particular. Concerning social development, the importance of rural roads was justified by highlighting their ability to help and rehabilitate drought-affected people.

As a consequence of this increasing focus on rural road, the first Sector Program
(SPI 1977/78-1981/82 G.C) was formulated and replaced the Highway Programs. The Sector Program (SP) expressed the government's intention to construct a "...vast network of systematized low-cost and low-standard roads..." and to unite the existing main highways with the projected rural roads. From a political perspective, the value attached to rural roads by the Derg regime can be interpreted as a means for raising political consciousness in the countryside or a way to enforce the regime's intrusion into the rural areas. However, until 1990 G.C, the Derg had increased the classified road network to 19,020 km (The Roads of Decentralization: The History of Rural Road Construction in Ethiopia, by Rony Emmenegger NCCR North-South Dialogue, no. 39 2012).

Table 2.1: Classification of Road Network and Growth before RSDP (Length in km)

Year	Asphalt	Growth Asphalt	Gravel	Growth Gravel	Rural	Urban	Total	Growth
1974	3360	-	5900	-	-	9260	9260	-
1975	3280	-2.38	6080	3.05	-	9360	9360	1.08
1976	3200	-2.44	6200	1.97	120	9400	9520	1.709
1977	3126	-2.31	6290	1.45	652	9416	10068	5.756
1978	3051	-2.4	6801	8.12	790	9852	10642	5.701
1979	3115	2.1	7328	7.75	1091	10443	11534	8.382
1980	3285	5.46	7328	0	1595	10613	12208	5.844
1981	3515	7	7430	1.39	1830	10945	12775	4.644
1982	3769	7.23	8532	14.83	2630	12301	14931	16.877
1983	3916	3.9	8532	0	3053	12448	15501	3.818
1984	4000	2.15	8738	2.41	3420	12738	16158	4.238
1985	4042	1.05	8788	0.57	3808	12830	16638	2.971
1986	4050	0.2	8989	2.29	4198	13039	17237	3.6
1987	4062	0.3	8994	0.06	5158	13056	18214	5.668
1988	4109	1.16	9270	3.07	5232	13379	18611	2.18
1989	4109	0	9270	0	5232	13379	18611	0
1990	4109	0	9287	0.18	5550	13396	18946	1.8
1991	4109	0	9298	0.12	5610	13407	19017	0.375
1992*	3542	-13.8	8966	-3.57	5573	12508	18081	-4.922
1993	3555	0.37	9011	0.5	5800	12566	18366	1.576
1994	3622	1.88	10100	12.09	7812	13722	21534	17.249
1995	3630	0.22	12000	18.81	8043	15630	23673	9.933
1996	3656	0.72	12133	1.11	9100	15789	24889	5.137

Source: ERA, Assessment of 15 Years Performance of Road Sector Development Program

2.2. Overview of Recent Road Network and Sector Policies in Ethiopia

Recognizing the importance of the road transport in supporting social and economic growth and its role as a catalyst to meet poverty reduction targets, the Federal Democratic Republic of Ethiopia (FDRE) has placed increased emphasis on improvement of the quality and size of road infrastructure in the country. To address constraints in the road sector, mainly low road coverage and poor condition of the road network, the

Government formulated the Road Sector Development Program (RSDP) in 1997 G.C. The RSDP has been implemented over a period of fifteen years and in four separate phases, as follows:

- RSDP I - Period from July 1997 to June 2002 (5 year plan);
- RSDP II - Period July 2002 to June 2007 (5 year plan);
- RSDP III - Period July 2007 to June 2010 (3 year plan);
- RSDP IV - Period July 2010 to June 2015 (5 year plan)

Over fifteen years of the RSDP, physical works consisting of rehabilitation and upgrading of trunk and link, construction of new link main access roads, construction of rural roads & community roads and maintenance of federal and regional roads has been carried out by ERA, Rural Roads Authorities (RRAs) and Woreda Road Desks and the community and municipalities. Also over fifteen years of RSDP series of policy and institutional reforms have been implemented in the sector. Government of Ethiopia has been major financer of RSDP followed by the Road Fund Office. Donors have supported RSDP in the past fifteen years including the World Bank, European Union, ADB, NDF, BADEA, OFID and the Governments of Japan, Germany, U.K. and Ireland. The Saudi Fund for Development, the Kuwait Fund and the Government of China have also joined the financing partnership since RSDP II. The recent partner which joined this effort is Abu Dhabi Fund. Fifteen years have passed since the launch of the RSDP. This report summarizes and highlights both the major accomplishments of the program over its fifteen years and also provides the two years performance of the RSDP IV.

2.2.1. Decisions on Road Placements

ERA applies a set of selection criteria for the RSDP when prioritizing between projects for new road constructions and upgrading of existing roads. All selected roads will go through a feasibility study to compare the total costs with the total benefits of each selected new road construction or upgrading project. Total project costs include the construction and maintenance cost of the road during the service period of the road. Benefits take into account reduction in vehicle operating and maintenance cost. This allows ERA to assess the Net Present Value of road projects and refine its projects selection and budget estimates. The weights used are shown as in Table 2.2 (International Growth Center, Working Paper 12/0696 September, 2012).

Table 2.2: ERA's Weights for Road Placements

Selection Criteria	Weights
New road projects	
Roads providing access to areas with economic development potential	20%
Roads leading to areas with surplus food and cash crop production	20%
Roads that link existing major roads	20%
Roads providing access to large and isolated population centers	30%
Roads that bring balanced development and that provide access to emerging regions	10%
Upgrading projects	
Roads with high traffic density	30%
Roads with better network connectivity	20%
Roads that are in poor condition	20%
Roads that link import/export and regional integration corridors	20%
Roads connecting investment routes (potential areas)	10%

Source: International Growth Center, Working Paper 12/0696 September, 2012

2.2.2. Fifteen Year Assessment of RSDP

Over the fifteen years of the RSDP, physical works have been undertaken on a total of 81,363 km of roads excluding routine maintenance work and community roads. The total budget for the planned works during this period amounted to ETB 107.8 billion (USD 6.4 billion). The total amount disbursed in the same period, is 101% of the planned target.

Table 2.3: Performance of Road Sector Development Program (RSDP)

Type of	**Physical Plan Vs. Accomplishment**			**Financial Plan Vs. Disbursement**		
Program	**Plan**	**Actual**	**% age**	**Budget**	**Disbursement**	**% age**
Total RSDP I	8908	8709	98	9813.0	7284.6	74
Total RSDP II	8486	12006	141	15985.8	18112.9	113
Total RSDP III	20686	19250	93	34643.9	34957.9	101
RSDP IV (2 yrs.)	57112	41398	72	47405.2	48107.2	101
Total RSDP (15 yrs.)	95192	81363	85	107847.9	108462.6	101

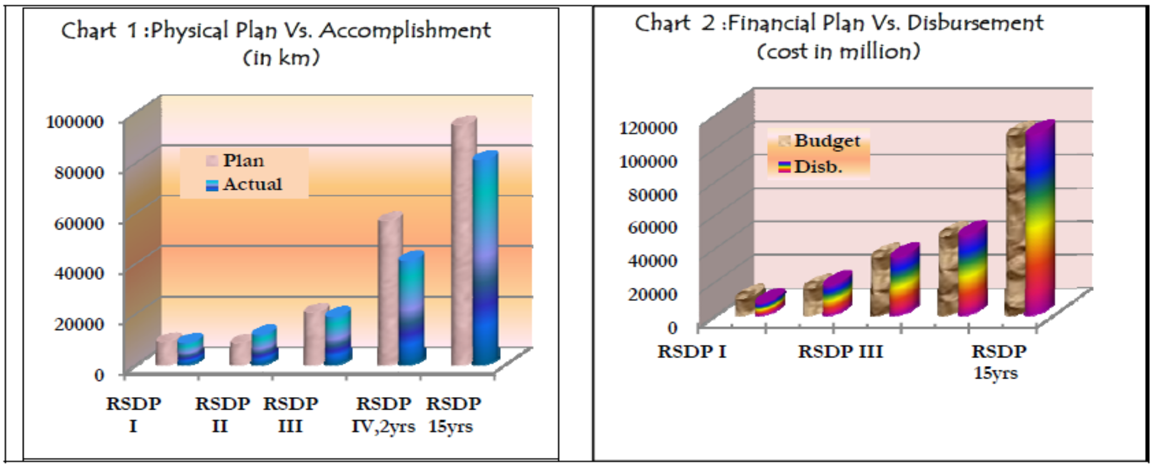


Figure 2.1: Performance of Road Sector Development Program (RSDP)
Source: ERA, Assessment of 15 Years Performance of RSDP**,** 2013 Addis Ababa.

2.2.3. Impact of Road Sector Development Program (RSDP)

As a result of road sector investment under the RSDP, the total road network of the country and its condition has improved. Overall, the RSDP is achieving satisfactory progress against its objectives and benchmarks. Substantial improvement has achieved in construction and upgrading the main road network and other arterial routes. Table 2.4 shows the progress made against selected indicators during the period of the RSDP. The impact of the RSDP on accessibility, quality, vehicle travel speed and mobility are discussed below as factors are indicators for the RSDP contribution to a wide range of growth inducing factors.

Table 2.4: Change in Selected Indicators

Indicators	1997	2012	Change (%)
Proportion of asphalt roads in good condition	17%	75%	341
Proportion of gravel roads in good condition	25%	57%	128
Proportion of rural roads in good condition	21%	57%	171
Proportion of total road network in good condition	22%	64%	191
Road Density/ 1000 sq. km	24km	57.3km	139
Road Density/ 1000 Population	0.49km	0.75km	53
Proportion of area more than 5km from all weather road	79%	56.4%	29
Average distance to all weather road	21km	8.7km	59
Road length (in km) excluding Woreda roads	26,550	56,100	111
Road length (in km) excluding Woreda roads	26,550	63,083	138

Source: ERA, Assessment of 15 Years Performance of RSDP, 2013 Addis Ababa

2.2.3.1. Impact on Accessibility

A. Road Network Expansion

In 1951 G.C, the total stock of road network was only 6400 km of which 3400 km was asphalt and the remaining 3000 km was gravel road. This entire network was found only in urban areas. When the Imperial regime lost power, the network has reached to 9160 km in 1973 G.C. On average, the network has been growing at a rate of 2.05 percent per annum over the period 1951-1973. During the Derg regime, 1974-1991, the stock road increased to 19017 km with a growth rate of 6.2 percent per annum (EDRI Working Paper 004, 2011 Addis Ababa). With the current EPRDF regime, the road network before the establishment of RSDP in 1997 was reached 26,550 km. Over the period 1991 to 1997 G.C, 7533 km of new road network was constructed.

Since its inception in 1997 G.C, the RSDP has focused on rehabilitation and expansion of the main paved and unpaved roads and important regional roads. The total road network has expanded from about 26,550 km at the beginning of the RSDP to its current (2012 G.C) 63,083 km including Woreda roads, increasing the road density from 24.1 to 57.3 km per 1000 sq. km and 0.46 to 0.75 km per 1000 population. The proper level of road network is assessed by road density, which is measured by road length per 1000 persons or by road length per 1000 km2. The growth of the classified road network and over the RSDP period is summarized in Table 2.5.

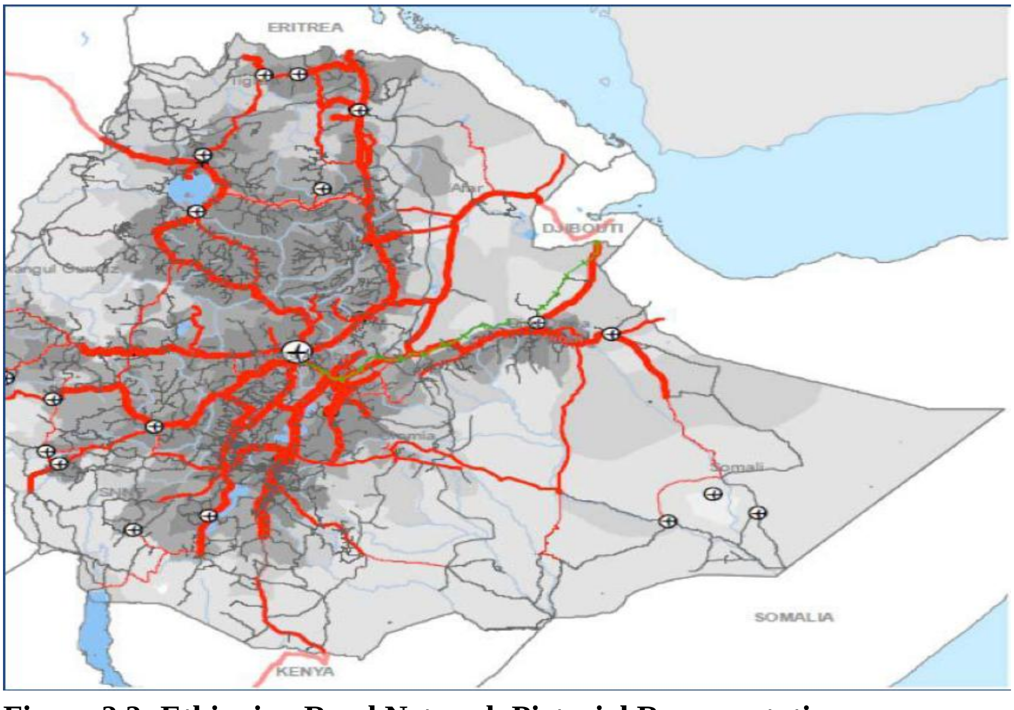


Figure 2.2: Ethiopian Road Network Pictorial Representation

Table 2.5: Growth of the Classified Road Network and Change in Road Density (1997 – 2012 G.C)

Year	Asphalt	Road Network Gravel	Rural	Woreda	Total	Growth Rate (%)	Road Density /1000 Popn	Road Density /1000km^2
1997	3708	12162	10680		26550	-	0.46	24.14
1998	3760	12240	11737		27737	4	0.46	25.22
1999	3812	12250	12600		28662	3.3	0.47	26.06
2000	3824	12250	15480		31554	10.1	0.50	28.69
2001	3924	12467	16480		32871	4.2	0.50	29.88
2002	4053	12564	16680		33297	1.3	0.49	30.27
2003	4362	12340	17154		33856	1.7	0.49	30.78
2004	4635	13905	17956		36496	7.8	0.51	33.18
2005	4972	13640	18406		37018	1.4	0.51	33.60
2006	5002	14311	20164		39477	6.6	0.53	35.89
2007	5452	14628	22349		42429	7.5	0.55	38.6
2008	6066	14363	23930		44359	4.5	0.56	40.30
2009	6938	14234	25640		46812	5.5	0.57	42.60
2010	7476	14373	26944		48793	4.2	0.58	44.39
2011	8295	14136	30712	854	53997	10.7	0.66	49.09
2012	9875	14675	31550	6983	63083	16.8	0.75	57.30
% age	**15.7**	**23.3**	**50.0**	**11.1**				

Source: ERA, Assessment of 15 Years Performance of Road Sector Development Program, January, 2013 Addis Ababa.

Although road density has increased, it has not improved that much as planned. At the year 2012 G.C, the road density is still much below the average road density of Africa, that is, 60 km per 1000 km^2 (ERA 2008b).

Table 2.6. Performance of Road Infrastructure of African Regions

Average Road Length per Capita, Km/ 1000 Persons			
Regions	**1960-1975**	**1976-1985**	**1986-1997**
Central	6.6	4.6	4.2
Eastern	3.3	2.8	2.2
Northern	3.8	2.9	2.4
Southern	7.1	6.3	5.6
Western	2.8	2.7	2.2

Source: Richaud, C. et al. (1999)

In spite of the successes achieved in improving the road density of Ethiopia, the current level is much below the different African regions in 1997 (Table 2.6). Ethiopia's road density is even less than the average road density of Eastern Africa. This indicates that even if there is much investment on construction and maintenance of roads, the need for further development in the sector remains (EDRI Working Paper 004, 2011 Addis Ababa).

B. Indicators of Accessibility

Accessibility, measured in terms of average distance from the road network and proportion of area farther than 5 km from an all-weather road, shows that substantial progress has been made in expanding the road network. Specifically, due to the construction of new roads, the average distance from a road has been reduced from 21km in 1997 to 8.7 km in 2012 G.C. The proportion of area farther than 5 km from an all-weather road, which was 79% in 1997, has been reduced to 56.4% in 2012 G.C.

C. Rural Access Index

Isolation is a key characteristic of poverty. Improved road access offers for the rural poor the ability to reach, visit or use services effectively and also contributes to the country's economy and development. Hence, improving access to transport for rural men and women is considered essential to promote rural development, to increase uptake of human development services (educational and health), to facilitate inclusion of different ethnic and other groups, to improve employment opportunities, and to stimulate growth for poverty reduction.

The Rural Access Index, RAI, measures the number of rural people who live within two kilometers (typically equivalent to a walk of 20-25 minutes) of an all-season road as a proportion of the total rural population. An "all-season road" is a road that is motorable all year round by the prevailing means of rural transport. Occasional interruptions of short duration during inclement weather (e.g. heavy rainfall) are accepted, particularly on lightly trafficked roads.

The RAI is one of the indicators of access that is recommended by the World Bank in 2003 and RAI is accepted by the African Ministers of Transport as a comparative measure of rural access in Africa. Table 2.7 shows the current level of accessibility of the rural population to an all-weather road as measured by the RAI and the progress made to improve accessibility through successive RSDP implementation years. The average RAI for the whole country is currently around 32%, a significant improvement when compared to the situation at the outset of the RSDP.

Table 2.7: Rural Access Index Values

Total Area ('000 km2)	Inhabited Area (80%)	Year	Rural Popn	Rural Popn. Density	Road Network	Rural Popn. Within 2km Access	Rural Access Index (%)
1,176	**796**	1997	46,493,600	58	26,550	6,203,041	13
		2002	53,776,000	68	33,297	8,997,887	17
		2007	61,259,132	77	42,429	13,061,124	21
		2010	65,680,187	83	48,793	16,104,158	25
		2011	68,143,000	86	53,997	18,483,797	27
		2012	70,135,000	88	63,173	22,264,514	32

2.2.3.2. Impact on Quality

Improving the condition of the road network remains a challenge. In the first year of the RSDP 52% of the road network was in poor condition and only 22% was in good condition. The rehabilitation, upgrading and maintenance intervention effort under the RSDP improved the proportion of the road network in good condition to 64 percent, with only 14% remaining in a poor condition. Roads in fair and poor condition are consistently declining. The trend in the condition of the classified road network in each phase of RSDP from 1997 to 2012 G.C is presented in Table 2.8 and Figure 2.3 below.

Table 2.8: Proportion of Different Condition of Roads in RSDP Program in %

Year	Good	Fair	Poor
1997	22	26	52
1998	23	26	51
1999	25	30	45
2000	28	32	41
2001	28	29	43
2002	30	30	40
2003	32	30	38
2004	37	28	35
2005	39	26	35
2006	47	22	31
2007	49	22	29
2008	53	20	27
2009	54	24	22
2010	56	23	21
2011	57	24	19
2012	64	22	14

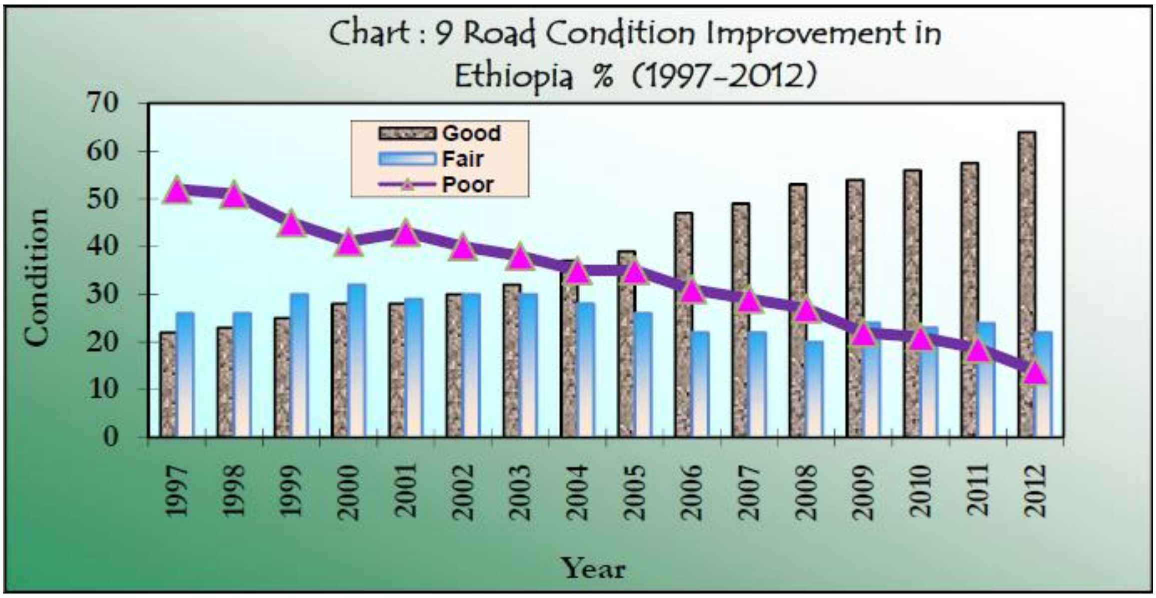


Figure 2.3: Proportion of Different Condition of Roads in RSDP Program in %
Source: ERA, Assessment of 15 Years Performance of RSDP**,** 2013 Addis Ababa

2.2.3.3. Impact on Vehicle Speed of Travel

Due to the improvement in road infrastructure by the RSDP between 1997 to 2009 G.C, the expected improvement in travel speed is as shown below in table 2.9.

Table 2.9: Expected Improvement in Speed of Travel

Pavement Type and Condition	Average Travel Speed	
	Before Rehabilitation or upgrading	After Rehabilitation or upgrading
Asphalt Roads	50km/hr.	70km/hr.
Federal Gravel Road	35km/hr.	45km/hr.
Regional Gravel Road	25km/hr.	35km/hr.
Earth Surfaced Roads	20km/hr.	35km/hr.
Federal Gravel or regional rural roads to Asphalt Roads	25km/hr-35km/hr.	70km/hr.

Source: ERA (From International Growth Center, Working Paper 12/0696, 2012).

2.2.3.4. Impact on Mobility

Classified traffic counts have been undertaken on most of the road network since 1950s. An assessment of traffic on the main roads reveals a rapid and continuous increase in the volume of motorized traffic. Vehicle kilometer of travel increased from 3.7 million to 14.3 million in 2012 G.C, showing 11% increase. Table 2.10 shows trend in vehicle kilometer during RSDP.

Table 2.10: Traffic Trend over the Period of the RSDP

Year	VKM	Growth Rate (%)
1997	3,771,565	-
1998	4,121,402	9
1999	4,499,496	6
2000	4,505,138	0.1
2001	4,711,689	5
2002	5,007,451	6
2003	5,604,395	12
2004	6,092,633	9
2005	6,769,424	11
2006	7,715,397	14
2007	9,324,985	21
2008	9,639,445	3
2009	11,752,452	22
2010	12,127,535	3
2011	14,356,250	11
Average	**7.4**	

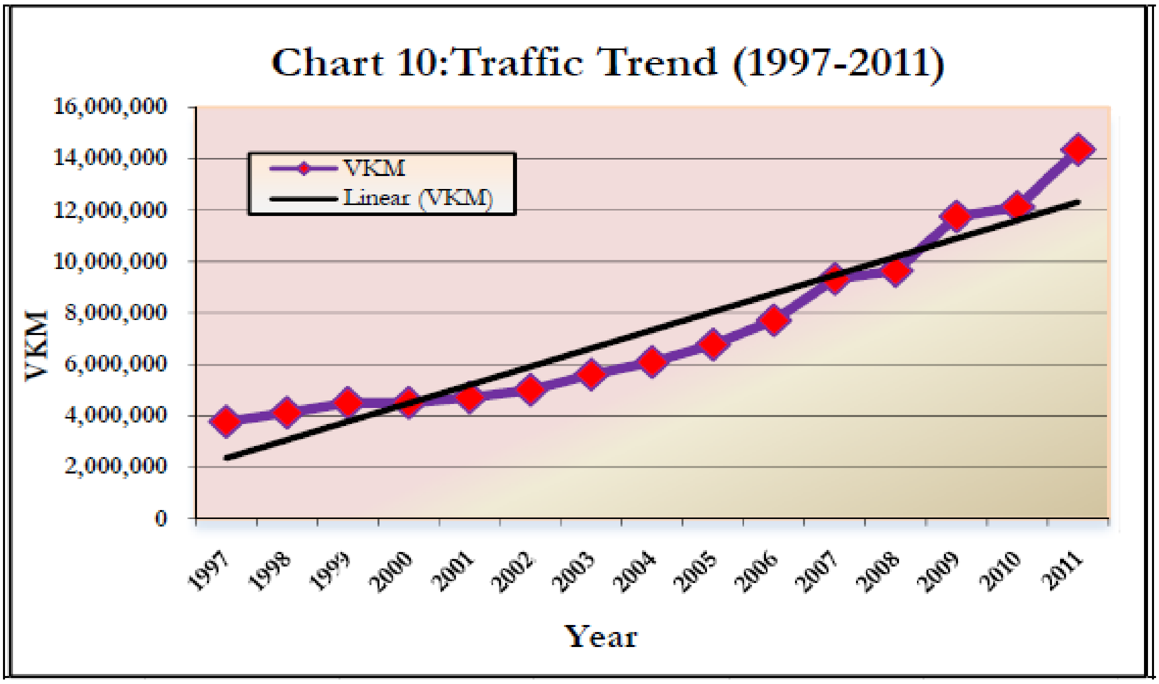


Figure 2.4: Traffic Trend over the Period of the RSDP

2.2.3.5. Impact on Vehicle Operating Cost

Impact of RSDP on Vehicle Operating Costs (VOC) is assessed using two scenarios - “with RSDP” and “without RSDP”. The following assumptions are made to estimate the impact of RSDP on transportation costs:

- The "with RSDP" analysis uses the current condition of the road network. The "without RSDP" analysis uses the condition of the road network in 1997 G.C and assumes no improvement throughout the past thirteen years;
- Both scenarios use the length of the Federal road network in 1997 G.C;
- Both scenarios use the current vehicle operating cost per kilometer per vehicle;
- The condition of the road network (roughness) is considered major determinant of vehicle operating cost per kilometer per vehicle,
- Vehicle operating cost per vehicle is calculated as a weighted average of each vehicle type considering current vehicle kilometer of travel as a weight.
- A vehicle is assumed to travel on the entire length of the road network a year.

The total vehicle operating cost and savings calculated for the "with RSDP" and "without RSDP" scenarios is presented in Table 2.11 showing that with the RSDP the VOC savings are around 12% and 9% on the paved and gravel road networks respectively.

Table 2.11: Vehicle Operating Cost Savings with RSDP

Scenario	**Surface Type**	**Condition**	**age %**	**In km**	**Weighted VOC Birr/Km/Veh)***	**Total VOC (Birr)**	**Saving (Birr)**
Without RSDP	Paved	Good	17	630	10.57	6,664.17	-
		Fair	39	1446	11.77	17,023.72	
		Poor	44	1632	14.06	22,940.80	
		Sub-Total	100	3708		46,628.69	
	Gravel	Good	25	3041	14.14	43,004.83	
		Fair	17	2068	16.09	33,266.72	
		Poor	58	7054	18.84	132,910.71	
		Sub-Total	100	12162		209,182.26	
With RSDP	Paved	Good	73	2707	10.57	28,616.71	
		Fair	15	556	11.77	6,547.59	
		Poor	12	445	14.06	6,256.58	
		Sub-Total	100	3708		41,420.88	
	Gravel	Good	53	6446	14.14	91,170.24	
		Fair	20	2432	16.09	39,137.32	
		Poor	27	3284	18.84	61,872.23	
		Sub-Total	100	12162		192,179.79	17,002.5

Source: ERA, Assessment of 15 Years Performance of RSDP**,** 2013 Addis Ababa.

2.3. Traffic Accident Situations in Ethiopia

Recently, Ethiopia has become one of the fastest growing non-oil producing economies in the world (AfDB, et al., 2012). As road transport is the main mode of transport, there has been a continuous increase in the vehicular population. Data from the Federal Transport

Authority shows that the motor vehicle fleet on average has grown by about 7 % per year from the year 2004 to 2008 (Ethiopian Roads Authority, 2011 Addis Ababa).

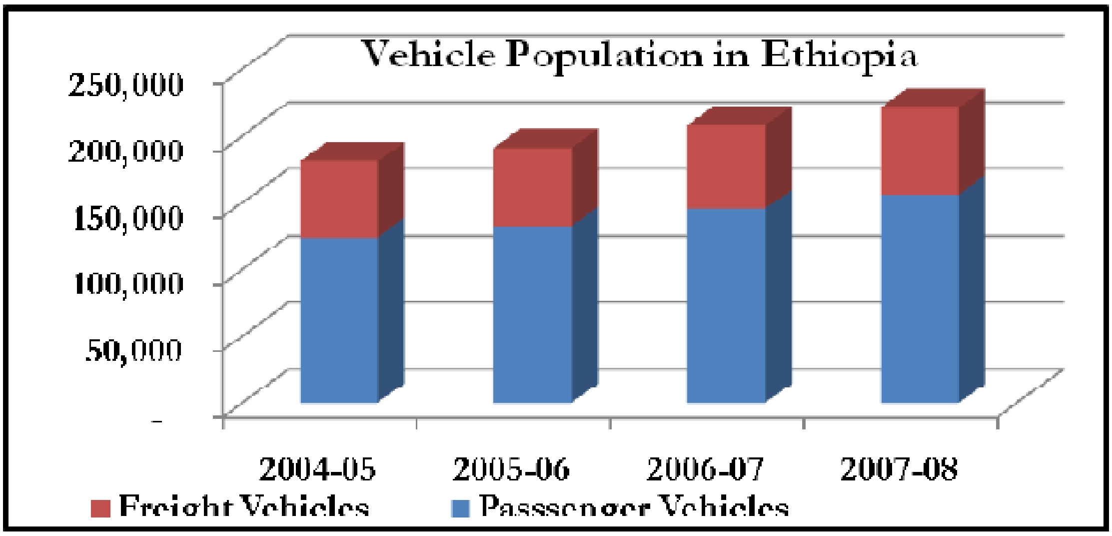


Figure 2.5: Vehicle Population Growth in Ethiopia

Hence, the construction of roads is one of the major focal areas of the government to fast-track economic growth. Although the vehicle population growth rate per annum is increasing, the number of total vehicles remains low compared to other developing countries. Currently, road density and number of vehicles per 1,000 population in Ethiopia are low when compared with other African countries as shown in Table 2.12.

Table 2.12: Paved Road Density and Motor Vehicle Population in Selected African Countries. (The World Bank, 2012; Yepes, Pierce, & Foster, 2009)

Description	Ethiopia	Uganda	Kenya	Ghana	Nigeria	Botswana	South Africa
Road Density by area, km/1000 km^2 in 2001	4	8	13	58	65	10	60
Motor vehicles per 1000 people in 2009	4	8	23	30	31	133	162

Despite having very low road network density and vehicle ownership, the country has a relatively high accident record which has been indicated as the worst example by different authors (Jacobs and Sayer, 1983; TRL and Ross Silcock Partnership, 1991; Downing et al., 1991). Figure 2-1 shows the alarming increasing trend of traffic accidents and fatalities at 17 % and 10 % per year respectively with vehicle fleet and road network in the country up to 2005/2006, but a sudden decrease in the recent couple of years.

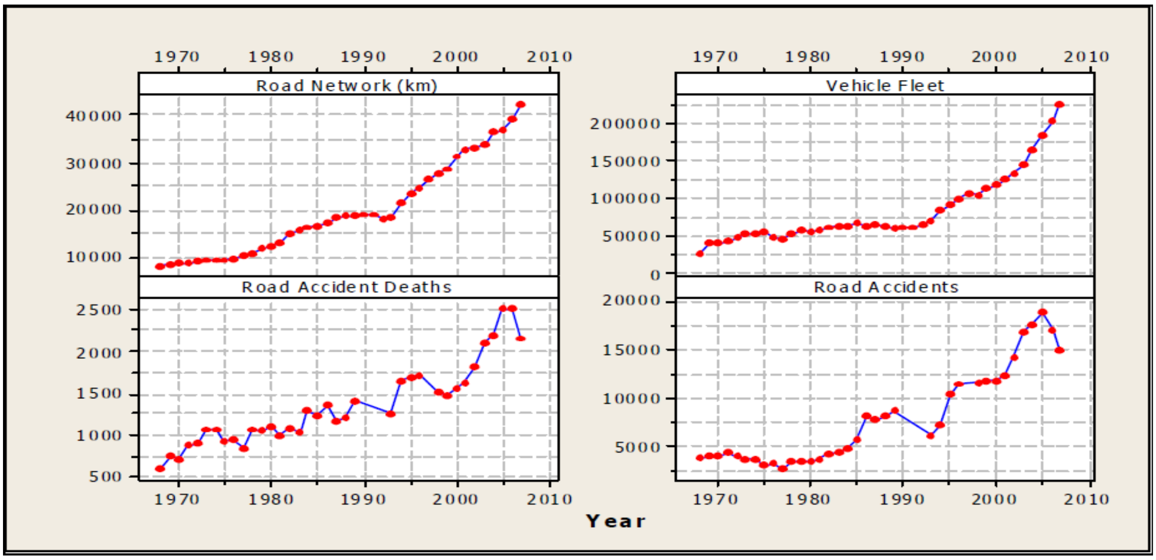


Figure 2.6: Trends of traffic accidents, vehicle fleet, and road network in Ethiopia (Data Source: Federal Police Commission; compiled by the consultant)

Six years (July 2005 - June 2011G.C) of police-reported crash data were analyzed, consisting of 12,140 fatal and 29,454 injury crashes on the country's road network. The 12,140 fatal crashes involved 1,070 drivers, 5,702 passengers, and 7,770 pedestrians, totaling 14,542 fatalities, an average of 1.2 road user fatalities per crash. An important and glaring trend that emerges is that more than half of the fatalities in Ethiopia involve pedestrians. The majority of the crashes occur during daytime hours, involve males, and involve persons in the 18-50 age group which is Ethiopia's active workforce. Crashes frequently occur in mid blocks or roadways. The predominant collision between motor vehicles and pedestrians was a rollover on a road tangent section. Failing to observe the priority of pedestrians and speeding were the major causes of crashes attributed by police. Trucks and minibus taxis were involved in the majority of crashes, while automobiles (small vehicles) were less involved in crashes relative to other vehicle types, partially because small vehicles tend to be driven fewer kilometers per annum. These data illustrate and justify a high priority to identify and implement effective programs, policies, and countermeasures focused on reducing pedestrian crashes.

2.3.1. Crashes by the Road User

The age range of drivers involved in crashes is shown in Table 2.13. The highest number of crashes (fatal, injury, and property damage) involved drivers in the 18–30 year age group (45%) and in the 31-50 year age group (35%). The drivers in the age group 18-30 were involved in more crashes, followed by the age group 31-50 (Misganaw & Gebre-Yohannes, 2011).

Gender also presents differentiation in crash involvement. Over the six years, male and female drivers were involved in 10,928 (90.02%) and 684 (5.63%) fatal crashes respectively. Gender in the remaining 528 (4.35%) fatal crashes was not recorded in the crash reports. There are two possible reasons for the high proportion of male drivers involved in crashes. Firstly, professional driving jobs are dominated by male drivers, especially for jobs in remote areas or those that involve nighttime driving. It is worth noting that female involvement in paid employment (or self-employment) is low in Ethiopia (Quisumbing & Yohannes, 2004). Kilometers travelled per annum by women as drivers are most probably lower than men. Unfortunately there is insufficient information on the gender split between drivers to enable rates to be calculated.

Table 2.13: Crashes in Ethiopia by Driver Age, Education and Gender, July 2005-June 2011

Driver Age	Fatal	Injury	Property	Total	%
Less than 18	342	775	766	1,883	1.8
18-30	6,005	14,182	25,624	45,811	44.5
31—50	3,853	9,027	23,491	36,371	35.3
More than 51	764	2,023	6,276	9,063	8.8
Unclassified age	1,176	3,447	5,279	9,902	9.6
Total	**12,140**	**29,454**	**61,436**	**103,030**	**100**
Driver Gender					
Male	10,928	25,628	54,005	90,561	87.9
Female	684	1,462	3,534	5,680	5.51
Unclassified	528	2,364	3,897	6,789	6.59
Total	**12,140**	**29,454**	**61,436**	**103,030**	**100**

Fatal and injury crashes totaled 41,594 over a six year period. The composition of fatalities and injuries was 22% and 78% respectively. Fatalities in terms of road users (drivers, passengers, and pedestrians) were 7.36%, 39.21%, and 53.43% respectively. In terms of gender, males accounted for 76.98% and females for 23.02% of the fatalities during the period. The population census in 2007 indicated that the split of males and females in the population was almost equal, so that male road users were greatly overrepresented in road fatalities per capita compared with females. As noted above, males are considered to be more likely than females to drive, although data on kilometers travelled by gender was not available, nor is activity based information available. Table 2.13 shows the fatal crashes according to male and female road users. The trends for male and female road users in various age categories are different. As mentioned previously, males were more vulnerable to death from crashes and roughly 15 times as many male drivers are killed compared with females. The difference is not as marked among passenger and pedestrian fatalities, where male deaths are approximately three times higher than female deaths. Among age groups, those aged under 18 account for only 21.6% of fatalities although they make up more than half the population, such that the 18-30 and 31-50 age groups account for two-thirds of fatalities. This is consistent with international reports that indicate that road traffic injuries are the second and third leading causes of death for age groups 15-29 and 30-44 (WHO, 2000).

Table 2.14: Fatalities for Road Users in Gender and Age Groups in Ethiopia July 2005-June 2011 E.C.

Age	**Drivers**		**Pedestrians**		**Passengers**		**Total**			
(yrs)	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**Total**	**%**
<18	45	6	1562	723	513	271	2120	1000	3120	21.4
18-30	506	28	1773	470	2262	612	4541	1110	5651	38.9
31-50	355	29	1565	418	1274	308	3194	755	3949	27.2
≥ 51	96	5	948	311	295	167	1339	483	1822	12.5
Total	1,002	68	5848	1992	4344	1358	11194	3348	14542	100

Table 2.15 also presents data on the average annual fatalities rate per 100, 000 inhabitants in these age group categories. Notably, even though these rates illustrate the gender and age group differences described above, they are not high compared with many other countries, but the overall rate of 3 road traffic deaths per 100,000 population is also considerably lower than the rate of 18 estimated by the latest Global Status Report on Road Safety (WHO, 2013). This six-fold discrepancy may be due to significant underreporting of crashes, and this requires further investigation.

Table 2.15: Population Demography in Gender and Age Groups in Ethiopia and AAFR of Inhabitants July 2005-June 2011 G.C.

Population in 2007 (Thousands)					**Average Annual Fatality Rate (AAFR) per 100,000 Inhabitants**		
Age in yrs	M	F	Total	%	M	F	Total
<18	19726	18742	38468	52.1	2	1	1
18-30	8658	9426	18084	24.5	9	2	5
31-50	5983	6005	11988	16.2	9	2	6
≥ 51	2918	2439	5358	7.3	8	3	6
Total	37285	36612	73897	100	5	2	3

(Population Census Commission, 2008)

2.3.2. Crashes by Road Environment

The absence of median strips or barriers also has a significant effect in increasing crashes as shown in Table 2.16. Usually, rural two-lane roads lack these physical barriers which separate opposing the incoming and outgoing traffic flows. Two-way, two-lane roads constitute the major proportion in of the road network in Ethiopia. According to the six years of data considered here, 59.95% of fatal crashes occurred on undivided roadways with two lanes. Dual carriageway and one-way roads accounted for 12.21% of fatal crashes. In the case of injury crashes, the former types accounted for 56.46% of the total injuries and the latter were responsible for 18.11%. The provisions of median barriers are dependent on traffic volume, which means there are few kilometers of such roads, almost all in Addis Ababa.

With respect to road alignment, 65.18% of fatal and 67.33% of injury crashes occurred on tangent (straight) road segments with flat terrain. Tangent roads with mild grade and flat terrain contributed to 9.6% of fatal and 9.5% of injury crashes. Adding these figures together, this means that 74.78% of fatal crashes and 76.83% of injury crashes occurred on tangent roads with almost flat terrain in the period July 2005-June 2011 (Table 2.16). These findings are in line with other studies conducted in Ethiopia (Misganaw & Gebre-Yohannes, 2011; Tulu, 2007). Crash probability usually increases in mountainous and escarpment terrain road sections (Council, 1998), but without traffic volume data it is difficult to confirm this result in Ethiopia.

Lighting conditions were important. As mentioned in Table 2.16, most crashes occurred in daytime with sufficient lighting conditions, which is similar to findings in other research (Saidi & Kahoro, 2001). Table 2.16 shows that 62.45% of fatal crashes and 68.22% of injury crashes occurred in daylight. When twilight and sunrise are included with the daylight category, with the crash proportion rises to 76.87% of fatal and 80.42% of injury crashes. Research elsewhere has found that high rates of pedestrian fatal crashes around twilight and sunrise (Griswold, Fishbain, Washington, & Ragland, 2011); however, it was not possible to check whether this applied in Ethiopia.

Table 2.16: Fatal and Injury Crashes in the Six Year Period by Lanes/Medians, Road Alignment, Junction Type and Illumination Conditions

Description	Fatal Crashes	%	Injury Crashes	%
Lanes/Medians				
One way	3020	24.88	6391	21.7
Undivided Two way	7278	59.95	16631	56.46
Double carriageway (median)	1482	12.21	5335	18.11
Two-way (divided with solid lines road marking)	236	1.94	727	2.47
Two-way (divided with broken lines road marking)	124	1.02	259	0.88
Total	**12140**	**100.00**	**29454**	**100**
Road Alignment				
Tangent road with flat terrain	7,913	65.18	19832	67.33
Tangent road with mild grade and flat terrain	1,166	9.60	2797	9.50
Tangent road with mountainous terrain and escarpments	348	2.87	816	2.77
Tangent road with rolling terrain	337	2.78	909	3.09
Gentle horizontal curve	587	4.84	1,325	4.50
Sharp reverse curve	525	4.32	1,069	3.63
Steep grade upward with mountainous terrain	515	4.24	990	3.36
Steep grade downward with mountainous terrain	669	5.51	1,478	5.02
Other	80	0.66	238	0.81
Total	**12,140**	**100.00**	**29,454**	**100**
Illumination conditions				
Daytime with sufficient daylight	7,581	62.5	20,094	68.22
Twilight	871	7.17	2,004	6.80
Sun rising	874	7.20	1,590	5.40
Night with sufficient light	1,293	10.7	2,470	8.39
Night with insufficient light	542	4.46	1,519	5.16
Night without light	781	6.43	1,407	4.78
Other	198	1.63	370	1.26
Total	**12,140**	**100.00**	**29,454**	**100**
Road junction type				
Midblock	8,565	70.55	21,977	74.61
Y-junction	1,570	12.93	2,030	6.89
T-junction	742	6.11	2,367	8.04
Roundabout	371	3.06	848	2.88
Four leg junction	539	4.44	1,600	5.43
Five leg junction	95	0.78	111	0.38
Rail crossing	34	0.28	68	0.23
Other	224	1.85	453	1.54
Total	**12,140**	**100.00**	**29,454**	**100**

Midblock road sections had a considerable share of fatal and non-fatal crashes in the six years, probably because much pedestrian crossing takes place in these sections. Overall, 70.55% of fatalities and 74.61% of non-fatal injury crashes occurred on midblock road sections, as shown in Table 2.16. By comparison, intersections were safer, which is contrary to the findings usually reported in the research literature (Tay & Rifaat, 2007). Marked and other crossing facilities are rare in midblock areas, which might result in increased fatal and non-fatal crashes.

2.3.3. Crashes by Collision Type

Most crashes occurred while vehicles were driving straight ahead on tangent road sections (68.69% of fatal crashes and 71.44% of injury crashes). In contrast, maneuvering at intersections, overtaking, U-turns, entering and exiting from driveways, and other types of maneuver contributed relatively less to the occurrence of fatal and non-fatal crashes.

During the six years, pedestrian collisions comprised 48.55% of fatalities, while rollovers accounted for 17.34%. For injuries, the respective figures were 53.16% and 17.17%. The high rate of pedestrian collisions is common in developing countries and has been attributed to factors including poor land use planning, poor pedestrian behavior, poor enforcement of traffic regulations, inadequacy of the road network and poor road maintenance, and inadequate provision of pedestrian facilities (Damsere-Derry, Ebel, Mock, Afukaar, & Donkor, 2010; Gwilliam, 2003; Nantulya & Reich, 2006; Shah & Silva, 2010). Moreover, there are many pedestrians, so if a vehicle is going to run into a road user, it in all likelihood be a pedestrian. Rollover crashes often occurred on horizontal curved sections of roads, however, most rollover crashes in Ethiopia occurred on tangent road sections. The causes of rollover crashes on tangent sections of roads could include speeding, which has been found to contribute as much as 45% to rollover crashes (Mcknight & Bahouth, 2011).

Not observing priority of pedestrians and speeding were major causes of fatal and non-fatal crashes. The two combined contributed to 44.80% and 45.89% of fatal and injury crashes respectively. Observational studies undertaken in Ethiopia indicate that disobeying traffic control devices is a major problem (Tesema, Abraham, & Grosan, 2005). This noncompliant behavior of drivers also extends to other causes of crashes. Some of those identified in the literature are 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 behaviour (Misganaw & Gebre-Yohannes, 2011). In contrast, drink driving and drug driving made non-significant contributions in terms of fatalities and injuries during this period. The figure might be non-significant due to the lack of testing for alcohol and drugs. WHO notes that Ethiopia undertakes little alcohol and drug testing (WHO, 2013).

2.3.4. Involvement of Vehicle Types in Crashes

Crashes were analyzed in terms of vehicle type, and findings indicated that commercial vehicles were involved in 38.4% of fatalities and 37.8% of injuries in the six-year period. Minibus taxis and buses were also involved in 34.5% of fatalities. However, these trucks and buses currently make up only 18.22% and 12.49% respectively of the vehicle population in the country. This is consistent with other research which has found that trucks were more involved in crashes in less developed countries (Mohan, 2002).

On the other hand, automobile vehicles had low fatality and injury records; however, there were significantly high numbers of property damage crashes during the period. This may be due to the lower annual kilometres travelled by this group of vehicles, however there are no data to confirm this. Vehicle roadworthiness may be a problem, since 36% of imported vehicles and 65% of the vehicle population have been found to have an age of over 15 years (Akloweg, et al., 2011). Given these figures, it is not surprising that vehicles aged over 5 years were involved in the majority of crashes in Addis Ababa (Akloweg, et al., 2011).

Table 2.17: Crashes by Collision and Vehicle Type

Description	Fatal Crashes	%	Injury Crashes	%
Collision Types				
Head –on collisions	604	4.98	608.98	4.48
Rear-end collisions	333	2.74	335.74	4.16
Broadside collision	284	2.34	286.34	2.85
Sideswipe collision	260	2.14	262.14	2.72
Rollover	2105	17.34	2122.34	17.17
Collision with pedestrians	5894	48.55	5942.55	53.16
Fall from vehicles	1024	8.43	1032.43	6.46
Collision with animals	609	5.02	614.02	4.23
Collision with roadside parked vehicles	219	1.8	220.8	1.49
Collision with road side objects	370	3.05	373.05	1.43
With Train	233	1.92	234.92	0.07
Others	100	0.82	100.82	0.74
Unknown	105	0.86	105.86	1.04
Total	**12140**	**100**	**12240**	**100**
Type of Vehicles				
Cycle and Motorcycle	451	3.71	1258	4.27
Automobile and Land Cruiser	1204	9.92	5606	19.03
Commercial Vehicle	5780	47.61	11124	37.77
Minibuses and Buses	4191	34.52	10569	35.88
Earth Moving	183	1.51	248	0.84
Rail	2	0.02	5	0.02
Animal Drawn Cart	48	0.40	126	0.43
Others	70	0.58	173	0.59
Unknown	211	1.74	345	1.17
Total	**12140**	**100.00**	**29454**	**100.00**

Characteristics of Police-reported Road Traffic Crashes in Ethiopia over a Six Year Period: Proceedings of the 2013 Australasian Road Safety Research, Policing & Education Conference 28th – 30th August, Brisbane, Queensland

2.4. Review of Studies on Highway Design Philosophy and Road Safety Audit

2.4.1. Highway Design Philosophy

Designing roads is a profession which needs different kinds of skills. First of all one uses the traffic engineering techniques. Secondly one uses notions about driver behaviour, how road users react on the road and its environment. And last but not least, one is guided by a design philosophy. This philosophy can be implicit, formed by intuition and experience, or it can be explicit, developed by research and evaluations. In fact a combination of two philosophies: 'sustainably safe traffic and transport system' and 'relation design' *(Safety Standards for Road Design and Redesign:* SAFESTAR Final Report November, 2002). In order to develop a better understanding on adverse effects of highway route selection and geometric design deficiencies on the road users, a comprehensive literature review were conducted focusing on its traditional and conventional tools as well as current and modern standards and basic design techniques for economical design of highway.

2.4.1.1. Factors Influencing Highway Design

Highway design is based on specified design standards and controls which depend on the following roadway system factors:

- Functional classification;
- Design hourly traffic volume and vehicle mix;
- Design speed;
- Design vehicle;
- Cross section of the highway, such as lanes, shoulders, and medians;
- Presence of heavy vehicles on steep grades;
- Topography of the area that the highway traverses;
- Level of service;
- Available funds;
- Safety and
- Social and environmental factors

These factors are often interrelated. For example, design speed depends on functional classification which is usually related to expected traffic volume. The design speed may also depend on the topography, particularly in cases where limited funds are available. In most instances, the principal factors used to determine the standards to which a particular highway will be designed are the level of service to be provided, expected traffic volume, design speed, and the design vehicle. These factors, coupled with the basic characteristics of the driver, vehicle, and road, are used to determine standards for the geometric characteristics of the highway, such as cross sections and horizontal and vertical alignments. For example, appropriate geometric standards should be selected to maintain a desired level of service for a known proportional distribution of different types of vehicles (*Traffic and Highway Engineering,* Nicholas J. Garber and Lester A. Hoel, 2010).

2.4.1.2. Highway Route Corridor Selection

Road Design, Construction and Maintenance require an approach depending on the terrain. The shortest road alignment is not necessarily the easiest, quickest or most economical option for construction and maintenance. Frequently, topography, slope stability, flood hazard and erosion potential are likely to be the most significant controls in the choice of the most suitable alignment and design of cross-section.

Variations in geology and slope greatly influence road design and hence the cost of construction, and these variations can occur over very short lengths of alignment. Geology, geomorphology and hydrology, therefore, are key factors in the design, construction and maintenance of roads in Ethiopia. An appreciation of these factors alone is not enough to construct roads in an environmentally sound way. Road geometry, earth works, retaining structures and drainage measures must be designed in such a manner as to cause the least impact on the stability of the surrounding slopes and natural drainage systems. Excessive blasting, cutting, side tipping of spoil and concentrated or uncontrolled surface water runoff can lead to instability and erosion. Although many of these effects are often unavoidable, the design and the construction method adopted should aim to minimize them (ERA Geometric Design Manual, 2002).

The data required for the decision process are usually obtained from different types of surveys, depending on the factors being considered. Most engineering consultants and state agencies presently involved in highway locations use computerized techniques to process the vast amounts of data's that are generally handled in the decision process. These techniques include remote sensing, which uses aerial photographs for the preparation of maps, and computer graphics, which is a combination of the analysis of computer-generated data with a display on a computer monitor.

A. Principles of Highway Route Location

The basic principle for locating highways is that roadway elements such as curvature and grade must blend with each other to produce a system that provides for the easy flow of traffic at the design capacity, while meeting design criteria and safety standards. The highway should also cause a minimal disruption to historic and archeological sites and to other land-use activities. Environmental impact studies are therefore required in most cases before a highway location is finally agreed upon (*Traffic and Highway Engineering*, Nicholas J. Garber and Lester A. Hoel, 2010).

B. General Guidelines for Route Location

There are certain guide-lines which must be borne in mind in selecting the alignment and locating the route. They are:

1. The route of a highway should be so selected that it can handle the traffic must efficiently and serve the inhabited localities.
2. It should be in conformity with the desired lines of traffic.
3. A direct alignment usually results in overall economy (construction, maintenance and operation). Economy in initial cost alone is not always the optimal solution. Economy in total transportation cost should be aimed at.
4. The gradients should not be steeper and curvature not sharper than the limiting values specified for different types of terrain. Excess of either or both may result in economy of initial cost, but will involve extremely high operation costs, time costs and accident costs.
5. The location should minimize the use of agricultural land. If a road already exists, it may be advisable to make use of the land already available to the minimum extent.
6. The location should involve the least impact on the environment including fauna, flora, and drainage system. Destruction of wooded area should be avoided.
7. The location should blend with the surrounding landscape of the area and should not be a scar on it.
8. The alignment should be located as far as possible along the edges of properties rather than through them.
9. Obstructions such as cemeteries, burning Ghats, places of worship, historical and archaeological monuments should be steered through them.
10. Proximity to schools, playgrounds and hospitals should be avoided.
11. Interference with utility services like electric transmission lines, water supply mains, sewers, other pipe-lines etc. should be avoided as far as possible.
12. Frequent crossing and re-crossing of railway lines should be avoided. Intersections at grade with railway lines should also be avoided. If the crossing point is selected where the railway line is in cutting, the cost of the over bridge can be minimized.
13. Villages and towns should as far as possible be bypassed as an alignment through them will increase traffic hazards, congestion and pollution.
14. Locate the highway close to sources of embankment materials and pavement materials.
15. Avoid marshy and low-lying land and areas having poor drainage.
16. Avoid areas subjected to subsidence due to mining operations.

17. Avoid areas liable to flooding.
18. Avoid costly and highly developed areas and locate the facility through undeveloped or blighted areas and along large parklands.
19. When the alignment has to cross major rivers, the crossing point should be fixed carefully and become obligatory. Crossings of major rivers (waterway exceeding 100m) may have to be at right angles to the river flow, thus subordinating the highway alignment of considerations of bridge siting. But crossings of medium/minor streams should generally be governed by the requirements of the highway proper. If necessary, such small structures could be made skew and located on flat curves.
20. When all other requirements are satisfied, the best location is one which results in the minimum of earthwork, and which is close to good quality fill materials for embankments (Principles and practices of Highway Engineering, by Dr. L.R and Dr. N.B. Lal, Fifth Edition 2012).

C. Computer Application in Routing of Road Using Least-Cost Path Analysis

Determining the best route through an area is one of the oldest spatial problems. This problem has recently been solved effectively using GIS and Remote Sensing technologies. During the last decade, a few attempts have been made to automate the route-planning process using GIS technology. Constructing a new road or railway, or aligning an old one can be very expensive, with costs depending on the alignment selected. Costs are increased by long structures, by large volumes of cut and fill, and by unbalanced cut and fill were discrepancy has to be dumped or borrowed (International Journal of Engineering Research and Applications Vol. 2, Issue 4, July-August 2012).

There are numerous environmental issues that need to be addressed to ensure that the alignment does not reduce bio-diversity or degrade the environment. The first step in producing high quality alignments depends on obtaining suitable data on geology, land use, slope, soil and drainage. In addition, there are issues such as land value and ownership, social and economic impact, and identifying environmentally sensitive areas (International Journal of Engineering Research and Applications Vol. 2, Issue 4, July-August 2012).

2.4.1.3. Geometric Design

Once a route has been selected for a new highway, or a decision has been made to perform major work on an existing facility, the next step is to establish the geometric design controls (Roger L. Brockenbrough, P.E. Editor). Geometric design is the process whereby the layout of the road through the terrain is designed to meet the needs of the road users. Therefore, the geometric design is an essential component in the design development of a highway (ERA Geometric Design Manual, 2002).

A. Geometric Design Principles

Geometric design deals with the dimensioning of the elements of highways, such as vertical and horizontal curves, cross sections, truck climbing lanes, bicycle paths, and parking facilities. The characteristics of driver, pedestrian, vehicle, and road are serve as the basis for determining the physical dimensions of these elements. For example, lengths of vertical curves or radii of circular curves are determined to assure that the minimum stopping sight distance is provided to highway users for the design speed of the highway. The fundamental objective of geometric design is to produce a smooth-flowing and safe highway facility, an objective that only can be achieved by providing a consistent design standard that satisfies the characteristics of the driver and the vehicles that use the road (*Traffic and Highway Engineering,* Nicholas J. Garber and Lester A. Hoel, 2010).

B. Horizontal Alignment

The horizontal alignment consists of straight sections of the road (known as tangents) connected by curves. The curves are usually segments of circles, which have radii that will provide for a smooth flow of traffic. The design of the horizontal alignment entails the determination of the minimum radius, determination of the length of the curve, and the computation of the horizontal offsets from the tangents to the curve to facilitate locating the curve in the field. In some cases, to avoid a sudden change from a tangent with infinite radius to a curve of finite radius, a curve with radii varying from infinite to the radius of the circular curve is placed between the circular curve and the tangent. Such a curve is known as a *spiral* or *transition curve.* There are four types of horizontal curves: simple, compound, reversed, and spiral (*Traffic and Highway Engineering,* Nicholas J. Garber and Lester A. Hoel, 2010).

Definitions of Terminologies of Reverse Curves, Broken-Back Curves and Compound Curves, Black-spot Road Segment and Black-spot Particular Areas.

Curves are more frequent in rugged terrain. Tangent sections are shortened, and a stage may be reached where successive curves can no longer be dealt with in isolation. Three cases of successive curves are (see Figure 2.7):

- Reverse Curve: is a curve followed by another curve in the opposite direction. The occurrence of abrupt reverse curves (having a short tangent between two curves in opposite directions) should be avoided. Such geometrics make it difficult for the driver to remain within his lane. It is also difficult to super elevate both curves adequately, and this may result in erratic operation.
- Broken-Back Curve: is a curve followed by another curve in the same direction. The "broken-back" arrangement of curves (having a short tangent between two curves in the same direction) should be avoided except where very unusual topographical or right-of way conditions dictate otherwise. Drivers do not generally anticipate successive curves in the same direction. This also creates problems with super elevation and drainage.
- Compound curve: is curves in the same direction, but without any intervening tangent section. The use of compound curves affords flexibility in fitting the road to the terrain and other controls. Caution should however be exercised in the use of compound curves, because the driver does not expect to be confronted by a change in radius once he has entered a curve. Their use should also be avoided where curves are sharp. Compound curves with large differences in curvature introduce the same problems as are found at the transition from a tangent to a small-radius curve. Where the use of compound curves cannot be avoided, the radius of the flatter circular arc should not be more than 50 percent greater than the radius of the sharper arc; i.e. R_1 should not exceed 1.5 R_2. A compound arc on this basis is suitable as a form of transition from either a flat curve or a tangent to a sharper curve, although a spiral transition curve is preferred.
- Switch-back or hairpin curves: are used where necessary in traversing mountainous and escarpment terrain. Employing a radius of 20m or less, with a minimum of 10m, they are generally outside of the standards for all road design standards DS1-DS10, and hence switch-back curves require a careful design to ensure that all design vehicles can travel through the curve.

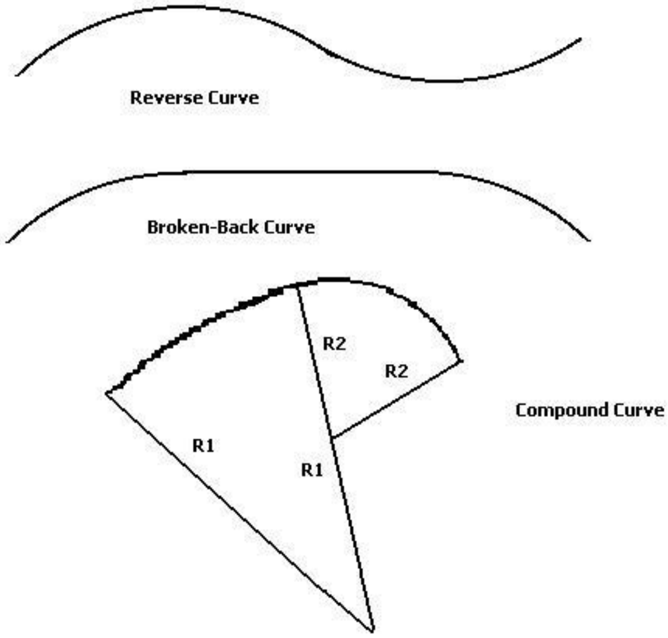


Figure 2.7: Reverse Curves, Broken-Back Curves, and Compound Curves

- Switch-back or hairpin curves: are used where necessary in traversing mountainous and escarpment terrain. Employing a radius of 20m or less, with a minimum of 10m, they are generally outside of the standards for all road design standards DS1-DS10, and hence switchback curves require a careful design to ensure that all design vehicles can travel through the curve.
- Transition Curves: The characteristic of a transition curve is that it has a constantly changing radius. Transition curves may be inserted between tangents and circular curves to reduce the abrupt introduction of lateral acceleration. They may also be used between two circular curves. Drivers employ their own transition on entry to a circular curve and hence transition curves contribute to the comfort of the driver in only a limited number of situations. For large radius curves, the rate of change of lateral acceleration is small and transition curves are not normally required. It can also be argued that transition curves are not a requirement for certain roads, particularly those of lower classification, where there is insufficient justification for the additional survey and design work required. Another possible warrant would be to consider spirals for roads where a significant portion of the curves has a super elevation in excess of 60 percent of the maximum super elevation. For Ethiopian roads, transition curves are a

requirement for trunk and link road segments having a design speed of equal to or greater than 80 km/hr (ERA Geometric Design Manual, 2002).

- ❖ Black-spot road segment: is a road segment which has a higher expected number of traffic crashes than other segment under the comparative study.
- ❖ Black-spot particular area: is an area which has a higher expected number of traffic crashes than other areas in a road segment under the study.

General Controls for Horizontal Alignment

The following general controls for horizontal alignment should be kept in view in sound design practice:

(i) Alignment should be as directional as possible.

(ii) Alignment should be consistent with the topography and should generally conform to the natural contours. A line cutting across the contours involves high fills and deep cuts, mars the landscape and is difficult for maintenance.

(iii) The number of curves should, in general, be kept to a minimum.

(iv) The alignment should avoid abrupt turns. Winding alignment consisting of short curves should be avoided, since it is the cause of erratic vehicle operation.

(v) A sharp curve at the end of a long tangent is extremely hazardous and should be avoided. If sharp curvature is unavoidable over a portion of the route selected, it is preferable that this portion of the road be preceded by successive sharper curves. Proper signage, well in advance of a sharp horizontal curve is essential.

(vi) Short curves giving the appearance of kinks should be avoided, especially for small deflection angles. The curves should be sufficiently long to provide pleasing appearance and smooth driving on important highways. They should be at least 150 meters long for a deflection angle of 5 degrees, and the minimum length should be increased by 30 meters for each 1 degree decrease in the deflection angle.

(vii) For a particular design speed, as large a radius as possible should be adopted. The minimum radii should be reserved only for the critical locations.

(viii) The use of sharp curves should be avoided on high fills. In the absence of cut slopes, shrubs, trees etc., above the roadway, the drivers may have difficulty in estimating the extent of curvature and fail to adjust to the conditions.

(ix) While abrupt reversal in curvature is to be avoided, the use of reverse curves becomes unavoidable in hilly terrain. When they are provided, adequately long transitional curves should be inserted for super-elevation run-off.

(x) Curves in the same direction separated by short tangents, say 300-500 meters long, are called broken-back curves. They should be avoided as they are not pleasing in appearance and are hazardous.

(xi) Compound curves may be used in difficult topography in preference to a broken-back arrangement, but they should be used only if it is impossible to fit in a single circular curve. To ensure safe and smooth transition from curve to curve, the radius of the flatter curve should not be disproportional to the radius of the sharper curve. A ratio of 2:1 or preferably 1.5:1 should be adopted.

(xii) The horizontal alignment should blend with the vertical harmoniously (*Principles and practices of Highway Engineering,* by Dr. L.R and Dr. N.B. Lal, Fifth Edition 2012)

C. Vertical Alignment

The vertical alignment of a highway consists of straight sections known as grades, (or tangents) connected by vertical curves. The design of the vertical alignment therefore involves the selection of suitable grades for the tangent sections and the appropriate length of vertical curves. The topography of the area through which the road traverses has a significant impact on the design of the vertical alignment.

Vertical curves are used to provide a gradual change from one tangent grade to another so that vehicles may run smoothly as they traverse the highway. These curves are usually parabolic in shape. The expressions developed for minimum lengths of vertical curves are therefore based on the properties of a parabola. Figure 2.8 illustrates vertical curves that are classified as crest or sag (*Traffic and Highway Engineering,* Nicholas J. Garber and Lester A. Hoel, 2010).

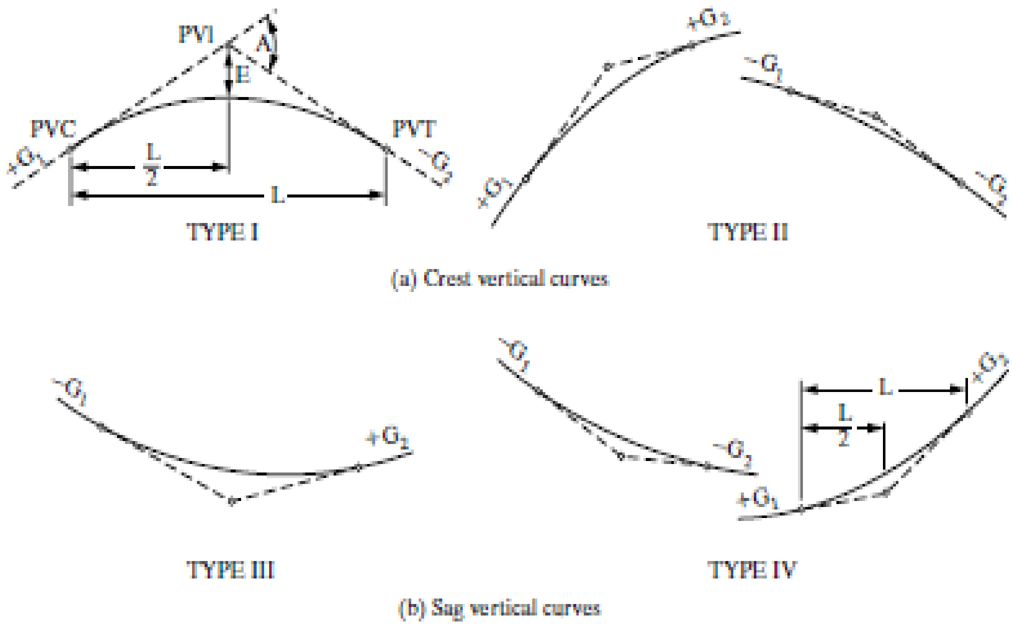


Figure 2.8: Types of Vertical Curves

G1, G2 = grades of tangents (%)

A = algebraic difference

L = length of vertical curve

PVC = point of vertical curve

PVI = point of vertical intersection

PVT = point of vertical tangent

General Controls for Vertical Alignment

The following general controls for vertical alignment should be kept in view kept in view while designing the vertical profile of a highway:

(i) The grade line selected should be smooth with gradual changes, consistent with the class of highway and terrain. Numerous breaks and short lengths of grades should be avoided.

(ii) The “roller-coaster” or “hidden type” of profile should be avoided as it is hazardous and aesthetically unpleasant.

(iii) Undulating Grade line involving substantial lengths of momentum grades, should be appraised for their effect upon traffic operation. Such profiles permit heavy trucks to operate at higher overall speeds than when an upgrade is not preceded by a down grade, but may encourage excessive speeds of trucks with consequent hazard to traffic.

(iv) A broken-back grade line (two vertical curves in the same direction separated by short section of tangent grade) should generally be avoided.

(v) On long continuous grades, it may be preferable to place the steepest grades at the bottom and flatten the grades near the top. Alternatively, the long grades may be broken by short intervals of flatter grades.

(vi) Intersections on grades should be avoided as far as possible. Where unavoidable, the approach gradients and the gradient through the intersections should be flattened to the maximum possible extent. (*Principles and practices of Highway Engineering,* by Dr. L.R and Dr. N.B. Lal, Fifth Edition 2012)

General Controls of Combination of Horizontal and Vertical Alignment

The following general controls should be kept in view in designing a highway for a combination of horizontal and vertical alignment

(i) The overall appearance of highway is enhanced with a judicious selection of horizontal and vertical elements. Best results are obtained when there is a proper balance between curvature and grades. Straight alignment or horizontal curves imposed on a road with steep or long grades or excessive curvature imposed on a road with a flat grade are both poor designs. A compromise between the two offers the best in safety, ease and uniformity of operation.

(ii) Vertical curvature superimposed upon horizontal curvature, or vice versa generally results in a pleasing effect.

(iii) From the safety point of view, sharp horizontal curvature should not be introduced at or near the top of a pronounced summit vertical curve. In such situations, the horizontal curve is made longer than the vertical curve.

(iv) Sharp horizontal curves should be avoided at or near the low point of a pronounced sag curve.

(v) On two-lane highways, the need for safe passing sections at frequent intervals and for an appreciable percentage of the length of the highway often supersedes the general desirability for combination of horizontal and vertical alignment. In these situations, it is desirable to have long straight sections to secure sufficient passing sight distance in design.

(vi) Horizontal curvature and vertical profile should be made as flat as feasible at highway intersections where sight distance is important and vehicles may have to slow down or stop.

(vii) On divided highways, variation in the width of the median and the use of separate profiles and horizontal alignments should be considered to derive design and operational advantages of one-way roadways (*Principles and practices of Highway Engineering*, by Dr. L.R and Dr. N.B. Lal, Fifth Edition 2012).

D. Cross-Section

A cross-section will normally consist of the carriageway, shoulders or curbs, drainage features, and earthwork profiles. The major elements of a cross-section are:

- Carriageway- the part of the road constructed for use by moving traffic, including traffic lanes, auxiliary lanes such as acceleration and deceleration lanes, climbing lanes, and passing lanes, and bus bays and lay-byes.
- Roadway- consists of the carriageway and the shoulders, parking lanes and viewing areas
- Earthwork profiles- includes side slopes and back slopes

For urban cross-sections, cross-section elements may also include facilities for pedestrians, cyclists, or other specialist user groups. These include curbs, footpaths, and islands. It may also provide for parking lanes. For dual carriageways, the cross-section will also include medians. (ERA Geometric Design Manual, 2002).

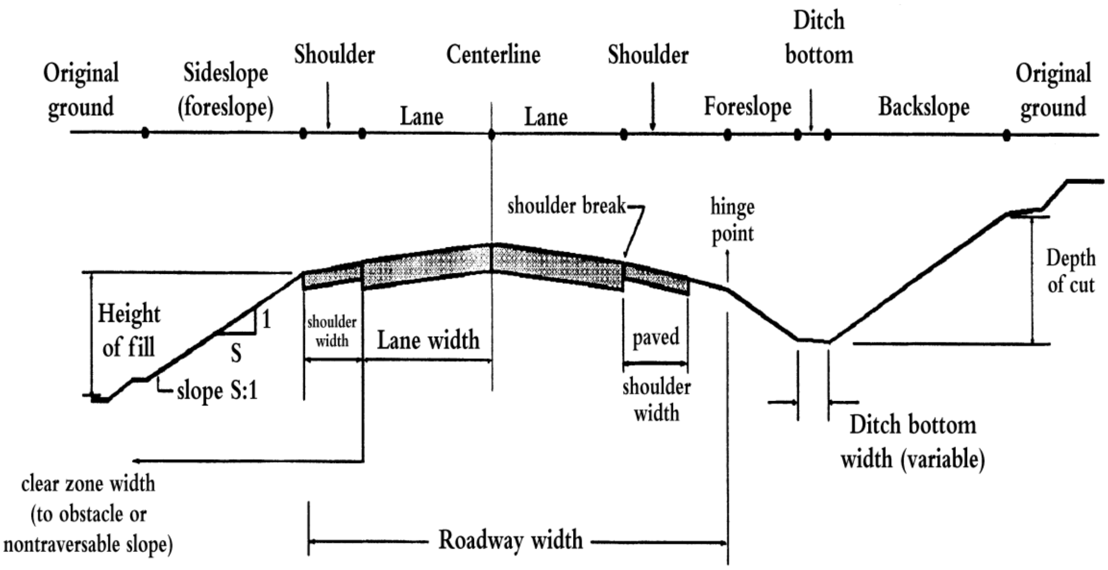


Figure 2.9: Cross Section Elements for Rural Two-Lane Highway.

General Controls for Cross-Section

Road width should be minimized to reduce the costs of construction and maintenance, while being sufficient to carry the traffic loading efficiently and safely. The following factors need to be taken into account when selecting the width of a road:

- ❖ Classification of the road – a road is normally classified according to its function in the road network; the higher the class of road, the higher the level of service expected and the wider the road will need to be.
- ❖ Traffic – heavy traffic volumes on a road means that passing of oncoming vehicles and overtaking of slower vehicles are more frequent, and therefore the paths of vehicles will be further from the center-line of the road, so the traffic lanes should be wider.
- ❖ Vehicle dimensions – normal steering deviations and tracking errors, particularly of heavy vehicles, reduce clearances between passing vehicles; wider traffic lanes are needed when the proportion of trucks is high.
- ❖ Vehicle speed – as speeds increase, drivers have less control of the lateral position of vehicles, reducing clearances, and so wider traffic lanes are needed. (Road Engineering for Development, Richard Robinson and Bent Thagesen, 2004)

2.4.2. Issues Involved In Transportation Safety

Several issues are involved in transportation safety. These include whether accidents should be referred to as crashes, the causes of transportation crashes, and the factors involved in transportation crashes.

2.4.2.1. Crashes or Accidents

"Accident" is the commonly accepted word for an occurrence involving one or more transportation vehicles in a collision that results in property damages, injury, or death.
The term "accident" implies a random event that occurs for no apparent reason other than "it just happened." Have you ever been in a situation where something happened that was unintended? Your immediate reaction might have been "sorry, it was just an accident."

In recent years, the National Highway Traffic Safety Administration has suggested replacing the word "accident" with the word "crash" because "crash" implies that the collision could have been prevented or its effect minimized by modifying driver behavior, vehicle design (called "crashworthiness"), roadway geometry, or the traveling environment. The word "crash" is not universally-accepted terminology for all transportation modes and is most common in the context of highway and traffic incidents.

In this research paper, both terms—“crashes” and “accidents”—are used because while “crash” is the preferred term, in some situations the word “accident” may be more appropriate.

2.4.2.2. What Causes Transportation Crashes?

The occurrence of a transportation crash presents a challenge to safety investigators.
In every instance, the question arises, “What sequence of events or circumstances contributed to the incident that resulted in injury, loss of lives, or property damage?” In some cases, the answer may be a simple one. For example, the cause of a single car crash may be that the driver fell asleep at the wheel, crossed the highway shoulder, and crashed into a tree. In other cases, the answer may be complex, involving many factors that, acting together, caused the crash to occur.

Based on these illustrations and other similar cases, it is possible to construct a general list of the categories of circumstances that could influence the occurrence of transportation crashes. If the factors that have contributed to crash events are identified, it is then possible to modify and improve the transportation system. In the future, with the reduction or elimination of the crash-causing factor, a safer transportation system is likely to result.

2.4.2.3. Factors Involved in Transportation Crashes

While the causes of crashes are usually complex and involve several factors, they can be considered in four separate categories: actions by the driver or operator, mechanical condition of the vehicle, geometric characteristics of the roadway, and the physical or climatic environment in which the vehicle operates. These factors will be reviewed in the following section.

A. Driver or Operator Action

The major contributing cause of many crash situations is the performance of the driver of one or both (in multiple vehicle crashes) of the vehicles involved. Driver error can occur in many ways, such as inattention to the roadway and surrounding traffic, failure to yield the right of way, and/or traffic laws. These “failures” can occurs a result of unfamiliarity with roadway conditions, traveling at high speeds, drowsiness, drinking, and using a cell phone or other distractions within the vehicle.

B. The Vehicle Condition

The mechanical condition of a vehicle can be the cause of transportation crashes. Faulty brakes in heavy trucks have caused crashes. Other reasons are failure of the electrical system, worn tires, and the location of the vehicle's center of gravity.

C. The Roadway Condition

The condition and quality of the roadway, which includes the pavement, shoulders, intersections, and the traffic control system, can be a factor in a crash. Highways must be designed to provide adequate sight distance at the design speed or motorists will be unable to take remedial action to avoid a crash. Traffic signals must provide adequate decision sight distance when the signal goes from green to red. Railroad grade crossings must be designed to operate safely and thus minimize crashes between highway traffic and rail cars. Highway curves must be carefully designed to accommodate vehicles traveling at or below the design speed of the road.

D. The Road User Other Than the Driver

Pedestrians, cyclists, drivers of animal-drawn vehicles are vulnerable road users and are commonly victims of road accidents.

E. The Environment

The physical and climatic environment surrounding a transportation vehicle can also be a factor in the occurrence of transportation crashes with the most common being weather. All transportation systems function at their best when the weather is sunny and mild and the skies are clear. Weather on roads can contribute to highway crashes; for example, wet pavement reduces stopping friction and can cause vehicles to hydroplane. Many severe crashes have been caused by fog because vehicles traveling at high speeds are unable to see other vehicles ahead that may have stopped or slowed down, creating a multivehicle pile-up. Geography is another environmental cause of transportation crashes. Flooded river plains, swollen rivers, and mud slides on the pavement have caused railroad and highway crashes (*Traffic and Highway Engineering*, Nicholas J. Garber and Lester A. Hoel, 2010).

2.4.2.4. The Social and Economic Costs of Road Traffic Injuries

Everyone killed, injured or disabled by a road traffic crash has a network of others, including family and friends, who are deeply affected. Globally, millions of people are coping with the death or disability of family members from road traffic injury. It would be impossible to attach a value to each case of human sacrifice and suffering, add up the values and produce a figure that captures the global social cost of road crashes and injuries.

The economic cost of road crashes and injuries is estimated to be 1% of gross national product (GNP) in low-income countries, 1.5% in middle-income countries and 2% in high-income countries. The global cost is estimated to be US$ 518 billion per year. Low-income and middle-income countries account for US$ 65 billion, more than they receive in development assistance.

Road traffic injuries place a heavy burden, not only on global and national economies but also household finances. Many families are driven deeply into poverty by the loss of breadwinners and the added burden of caring for members disabled by road traffic injuries. By contrast, very little money is invested in preventing road crashes and injuries, even though many interventions that would prevent crashes and injuries are well known, well tested, cost-effective and publicly acceptable (World report on road traffic injury prevention, 2004: summary).

2.4.3. Road Safety Audit (RSA)

"Road crashes are a worsening global disaster destroying lives and livelihoods, hampering development and leaving millions in greater vulnerability" (World Disaster Report-International Federation of Red Cross and Red Crescent Societies, 1998).

The Road Safety Audit is a formal systematic road safety assessment or "checking" of a road or a road scheme. It is a systematic procedure that brings traffic safety knowledge into the road planning and design process to prevent traffic crashes. This is usually carried out by an independent qualified auditor or a team of auditors who report on ways of minimizing risks to road users (ERA, Road Safety Audit Manual September, 2004).

The RSA concept was originally developed and introduced in the United Kingdom in the mid to late 1980s. The benefits of RSA were soon recognized around the world and many countries have since established their own similar systems. RSAs can produce significant benefits at low cost if carried out in a formal and coordinated manner at all stages in the planning, design and implementation of a road project. The process requires co-operation, management commitment, skilled auditors, and an on-going training program (Road Safety Manuals for Africa: African Development Bank, Department of Transport and ICT, OITC July, 2014).

The Road Safety Audit can be applied to all kinds of road projects such as new road construction as well as rehabilitation of existing roads. It can be applied to small and large projects and used on rural as well as urban roads. The RSA can be applied to specific operating and maintenance activities on existing roads as well as for systematic assessment or road safety aspects on existing roads and road networks.

The Road Safety Audit is also focused only on “accident prevention” and does not usually address the separate issue of “accident reduction”. For safe road networks to exist, it is necessary to carry out both accident prevention (using the RSA) and accident reduction (using hazardous location improvement programs). The RSA alone cannot solve all safety concerns but can play an important part in preventing the circumstances that can lead to road accidents (ERA, Road Safety Audit Manual September, 2004).

2.4.3.1. Benefits and Costs of Conducting a Road Safety Audit

It is evident that the benefit of undertaking RSA outweighs the cost incurred to conduct it. In the UK, for instance, the Lothian Regional Council has estimated the benefit-cost ratio of the RSA as being 15:1, while TRANSIT New Zealand has estimated the benefit cost ratio as 20:1. Consequently, there seems to be evidence from developed countries that significant benefit can result from introducing the RSA procedures. The benefit-cost ratio of such work in developing countries is likely to be even higher as the opportunity for avoidance of serious safety problems is even greater in the developing world where the road networks and road design are sometimes at an early stage of development (ERA, Road Safety Audit Manual September, 2004).

2.4.3.2. Highway Design for Road Safety

Whenever new roads are constructed, or existing roads are taken up for improvement the features of the highway must be designed with a clear objective of enhancing safety. Some of the aspects that need attention are listed below.

1. The design speed for the highway should be carefully selected, relating it to the terrain and road class. It is common to use 85^{th} percentile speed for design.
2. All roads must have the minimum stopping sight distance.
3. Overtaking sight distance is costly to provide. As large a percentage of the length as is consistent with economy should be designed for overtaking sight distance. Wherever overtaking is prohibited, suitable signs should be erected.

4. Horizontal curves are common accident spots. Sharp curves permit accident spots. Sharp curves permit low speeds and large radii curves cater to high speeds. It should be the endeavor of the designers to provide as large a radius as possible, taking recourse to minimum and ruling radii only when constrained by site conditions.
5. Transitional ends to circular curves enable the vehicle to enter the curve from the straight gradually. They must be provided wherever they are needed.
6. For a vehicle to negotiate any curve at the desired speed, the road should have adequate super elevation. Deficiency in super elevation can cause serious accidents.
7. To enhance the safety of narrow roads, good shoulders may be provided.
8. Shoulders should be of adequate width and material. They should be at the same level as the pavement if it has the same surface to the pavement. Excessive shoulder “drop-off”, a common feature of most roads, are a serious safety hazard. As part of routine maintenance, it must be ensured that there is no difference in levels of the pavement edge and the adjacent shoulder.
9. The vertical alignment should be designed with the provision of suitable shock-free vertical curves. The vertical curves should be made to blend homogeneously with the horizontal curves. It is a good practice to design the vertical curves to be fully contained with the horizontal curves.
10. For a vehicle to negotiate a curve at the desired speed, the road should have adequate super-elevation. Deficiency in super-elevation can cause the vehicle to go off the desired path.
11. Broken-back horizontal curves, i.e., curves in the same direction, separated by a short straight distance, should be replaced by a single curve. The minimum tangent length of 10 seconds travel time should be ensured if broken-back curves are unavoidable.
12. On long sections of roads with steep gradients, separate (auxiliary) climbing lanes are desirable, so that smaller vehicles like cars can safely overtake heavily loaded trucks.
13. Embankment side slopes should be as flat as possible so that errant vehicles accidentally leaving the road have a good chance of survival. For low embankments up to 1.5m height, a flat slope of 4:1 is desirable. For embankments

of large heights, a variable cross-section of side slopes starting from 2:1 at the top and ending at 4:1 at the ground level is suggested.

14. The texture of the pavement surface should be sufficiently rough to prevent skidding.
15. Road signs give advance warning to the driver of the road condition ahead. They should be made part of the road design for enhancing safety.
16. Road markings, reflectorized for night visibility, guide and assist the driver to safely negotiate the road.
17. Reflectorized road delineators are useful especially at night time.
18. Safety barriers are intended to prevent vehicles going off the road and deflect them back on their course. The barriers absorb the impact and deflect the vehicle. Barriers can be of a steel trough plate bolted to a steel post or of cement concrete. Barriers are provided at high embankments, on medians, and to protect vehicles from hitting electric posts, bridge abutments and piers.
19. Roads (particularly city streets) should be illuminated adequately.
20. Pedestrian sidewalks should preferably be raised above the road level by providing curbs and pedestrian guard rails.
21. Junction designs should incorporate good features such as channelization, acceleration and deceleration lanes, separate right turning pockets, signages and markings.
22. Traffic impact Attenuators should be provided wherever warranted. (Principles and practices of Highway Engineering Including Expressways and Airport Engineering, by Dr. L.R and Dr. N.B. Lal, Fifth Edition 2012)

2.4.3.3. Effectiveness of Safety Design Features

The document, *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan,* published by the Transportation Research Board (TRB) consists of several guides, each of which gives a set of objectives and strategies to improve safety at specific locations. Table below gives some of these objectives and strategies for a few locations.

Summary of Research Results on Safety Effectiveness of Highway Design Features

The Federal Highway Administration (FHWA) has also published a series of reports that summarize the results of research dealing with safety effectiveness of highway design features. These reports provide useful information about the relationship between crashes and highway geometrics. These results generally support the strategies given in Table

2.18 for reducing crashes at specific locations. Among the features to be considered in this research reports are (1) alignment, (2) cross sections, (3) intersections, and (4) pedestrians and bicyclists. Research results that spanned a 30-year period were examined, and in some instances, studies dating before 1973 were found to be the most definitive available. Design features are discussed in the following sections based on the information from these FHWA reports.

Table 2.18: Objectives and Strategies for Different Crash Types

Crash Types	
Strategies	***Objectives***
Collisions with Trees in Hazardous Locations	
Prevent trees from growing in hazardous locations	Develop, revise, and implement hazardous locations guidelines to prevent placing trees in hazardous locations (T) Develop mowing and vegetation control guidelines (p) Remove trees in hazardous locations (P)
Eliminate hazardous condition and/or reduce severity of the crash	Shield motorists from striking trees (P) Modify roadside clear zone in vicinity of trees (P) Delineate trees in hazardous locations (E)
Head-On Collisions	
Keep vehicles from encroaching into opposite lanes	Install centerline rumble strips for two-lane roads (T) Install profiled thermo-plastic strips for centerlines (T) Provide wider cross-sections for two-lane roads (T) Provide center two-way, left-turn lanes for four and two-lane roads (T) Reallocate total two-lane roadway width (lane and shoulder) to include a narrow buffer median
Minimize the likelihood of crashing into an oncoming vehicle	Use alternating passing lanes or four-lane sections at key locations (T) Install median barriers for narrow-width medians on multilane roads (T)
Collisions on Horizontal Curves	
Reduces likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	Provide advance warning of unexpected changes in horizontal curves (T) Enhance delineation along the curve Install shoulder and centerline rumble strips (T) Provide skid-resistant pavement surfaces (T) Improve or restore super-elevation (P) Widen roadway (T)

Table 2.18 Objectives and Strategies for Different Crash Types

Collisions on Horizontal Curves	
Minimize adverse consequences of leaving roadway at the horizontal curve	Design safer slopes and ditches to prevent rollovers (P) Remove/relocate objects in hazardous Locations Delineate roadside objects (E) Improve design and application of barrier and attenuation systems (T)
Collisions Involving Pedestrians	
Reduce pedestrian exposure to vehicular traffic	Provide sidewalks/walkways and curb ramps Install or upgrade traffic and pedestrian refuge islands and raised medians Install or upgrade traffic and pedestrian signals
Improve sight distance and/or visibility between motor vehicles and pedestrians	Provide crosswalk enhancements Signals to alert motorists that pedestrians are crossing Eliminate screening by physical objects
Reduce vehicle speeds	Implement road narrowing measures Install traffic calming road sections Install traffic calming intersections
Unsignalized Intersection Collisions	
Improve management of Access near Unsignalized Intersections	Implement driveway closures/ relocations (T) Implement driveway turn restrictions (Y)
Reduce frequency and severity Section conflicts through geometric design	Provide left-turn lanes at intersections (T) Provide offset left-turn lanes at intersections (T) Provide right- and left-turn acceleration lanes at divided highway intersections (T) Restrict or eliminate turning maneuvers by signing or channelization or closing median openings

(P) Proven, strategy has been used and proved to be effective.

(T) Strategy has been implemented and accepted as a standard or standard approach but valid evaluation not available.

(E) Experimental, strategy has been suggested and considered sufficiently promising by at least one agency.

SOURCE: Adapted from Guidelines for the Implementation of the AASHTO Strategic Highway Safety Plan, National Cooperative Highway Research Program, NCHRP, Transportation Research Board, Washington, D.C., 2004.

Alignment

The design of the vertical alignment (which includes tangent grades and sag or crest vertical curves) is influenced by consideration of terrain, cost, and safety. Generally, crash rates for downgrades are higher than for upgrades. One study reported that only 34.6 percent of crashes occurred on level grade, whereas 65.4 percent occurred on a grade or at the location where grades change.

The design of the horizontal alignment (which consists of level tangents connected by circular curves) is influenced by design speed and super elevation of the curve itself. Crash rates for horizontal curves are higher than on tangent sections, with rates ranging between 1.5 and 4 times greater than on straight sections.

Cross - Sections

One of the most important roadway features affecting safety is the highway cross section. Cross-section elements (including through and passing lanes, medians, and left-turn lanes) may be added when a two-lane road is inadequate, possibly improving both traffic operations and safety. Safety improvements in the highway cross section are usually focused on two-lane roads, with the exception of clear zone treatments and median design for multilane highways.

In general, wider lanes and/or shoulders will result in fewer crashes. A 1987 study by the FHWA measured the effects of lane width, shoulder width, and shoulder type on highway crash experience, based on data for approximately 5000 miles of two-lane highway. Related crashes include run-off-road, head-on, and sides-wipe occurrences.

Table 2.19: Effect of Lane Widening for Related Crash Types on Two-Lane Rural Roads

Amount of Lane Widening (ft.)	*Crash Reduction (percent)*
1	12
2	23
3	32
4	40

SOURCE: *Safety Effectiveness of Highway Design Features,* Volume II, U.S. Department of Transportation, FHWA, Washington, D.C., November 1992.

Not all crash types are “related” to geometric roadway elements. For example, if a lane is widened by 2 ft (from 9 ft to 11 ft), a 23 percent reduction in related crashes can be expected. Table 2.19 lists the percentage reduction in crash types related to lane widening. Table 2.20 provides similar results for shoulders. For example, if an unpaved shoulder is widened by 6 ft (from 2 ft to 8 ft), and the shoulder is paved, then a 40 percent reduction in related crash types can be expected, assuming that other features such as clear zone and side-slopes are unaltered. If both pavement and shoulder-width improvements are made simultaneously, the percentage reductions are not additive. Rather, the contribution of each is computed assuming that the other has taken effect.

Table 2.20: Effect of Shoulder Widening for Related Crash Types on Two-Lane Rural Roads

	Crash Reduction (percent)	
Shoulder Widening per Side (ft)	Paved	Unpaved
2	16	13
4	29	25
6	40	35
8	49	43

SOURCE: *Safety Effectiveness of Highway Design Features*, Volume III, U.S. Department of Transportation, FHWA, Washington, D.C., November 1992.

Factors that convert total number of crashes to number of related crashes (RC) are shown in Table 2.21.

Table 2.21: Ratio of Cross-Section Related Crashes to Total Crashes on Two-Lane Rural Roads

	Terrain Adjustment Factors		
ADT (VPD)	Flat	Rolling	Mountainous
500	0.58	0.66	0.77
1,000	0.51	0.63	0.75
2,000	0.45	0.57	0.72
4,000	0.38	0.48	0.61
7,000	0.33	0.40	0.50
10,000	0.30	0.33	0.40

Note: Related crashes include run-off-road, head-on, and opposite-direction and same-direction sideswipe. (SOURCE: *Safety Effectiveness of Highway Design Features)*

Intersections

Intersections represent the site of most urban motor vehicle crashes in the United States. The number of crashes at intersections has increased by 14 percent over a 20-year period. This result is not surprising, since intersections are the confluence of many vehicle and pedestrian paths that may conflict with each other. An encouraging trend, however, is the reduction in severity of intersection crashes, such that fatal crashes have reduced by 11 percent over the same 20-year period, to 28 percent of the total. The reduction in fatalities is the result of improvements in intersection design, use of passenger restraints, separation of vehicles from pedestrians, enhanced visibility, and improvements in traffic control devices.

Pedestrian Facilities

The safety of pedestrians is of great concern to traffic and highway engineers. Efforts to reduce pedestrian and bicycle crashes involve education, enforcement, and engineering measures, as is the case for motor vehicle crashes. The principal geometric design elements that are used to improve pedestrian safety are (1) sidewalks, (2) overpasses or tunnels, (3) raised islands, (4) auto-free shopping streets, (5) neighborhood traffic control to limit speeding and through traffic, (6) curb cuts that assist wheelchair users and pedestrians with baby carriages, and (7) shoulders that are paved and widened. Other traffic control measures that may assist pedestrians include crosswalks, traffic signs and signals, parking regulations, and lighting (*Traffic and Highway Engineering,* Nicholas J. Garber and Lester A. Hoel, 2010).

Traffic Calming

Traffic calming can be defined as the improvement of the traffic situation by reducing traffic speeds and perhaps numbers of vehicles particularly in residential areas, with emphasis on the safety of pedestrians, cyclists, and vulnerable road users, such as children or elderly. Traffic calming commonly includes speed humps, special warning signs, horizontal carriageway deflection and road narrowing. It has been shown that when pedestrians are hit by vehicles at a given speed:

- 95% survive at speeds up to 32 km/hr
- 55% survive at speeds up to 48 km/hr
- 15% survive at speeds up to 65 km/hr

And also the use of traffic calming to ensure low speeds can have a pronounced effect on reducing the severity of injury in accidents. Because of this, it has proved to be popular with engineers and residents (Road safety Guidelines for the Asian and Pacific Region: *Safe planning and Design of Roads).*

Median Safety Barrier

Median safety barriers physically separate opposing lanes of traffic. This helps stop vehicles travelling into opposing traffic lanes. The barriers can also be used to limit turning options for vehicles, and shift these movements to safer locations. Median barriers can reduce injuries by 50 per cent but their use must be considered carefully because they may increase speeds and reduce space for other road users.

Roadside Safety Barrier/Guard Rail

Where space permits, roadside safety barriers can be used to stop 'out of control' vehicles from leaving the road and hitting roadside hazards or rolling down slopes. Safety barriers do not reduce the number of run-off-the-road accidents, but can reduce the severity of these accidents. They are designed to absorb the impact of a crash and minimize injuries. Safety barriers can reduce injuries by 40 per cent (Tony Bliss, World Bank Global Road Safety Facility. Safe Roads for Development).

Special Facilities for Heavy Vehicles on Steep Grades

Statistics indicate a continual increase in the annual number of vehicle-miles of large trucks on the nation's highways. Large trucks as having different operating characteristics than those of passenger cars, a difference that increases with their weight and size. For example, as the grade of a highway section increases, the presence of trucks become more pronounced. Thus, it becomes necessary to consider the provision of special facilities on highways with steep grades where high volumes of heavy vehicles exist. The most common facilities that address this problem are climbing lanes and emergency escape ramps.

Climbing Lanes

A climbing lane is an extra lane in the upgrade direction for use by heavy vehicles whose speeds are significantly reduced by the grade. A climbing lane eliminates the need for drivers of light vehicles to reduce their speed when they encounter a heavy slow-moving vehicle. Because of the increasing rate of crashes directly associated with the reduction in speed of heavy vehicles on steep sections of two-lane highways and the significant reduction of the capacity of these sections when heavy vehicles are present, the provision of climbing lanes should be considered.

The need for a climbing lane is evident when a grade is longer than its critical length, defined as the length that will cause a speed reduction of the heavy vehicle by at least 10 mi/hr. The amount by which a truck's speed is reduced when climbing a steep grade depends on the length of the grade. For example, the speed of a truck entering a grade of 5 percent at 55 mi/h will be reduced to about 43 mi/h for a grade length of 1000 ft and to about 27 mi/h for a grade length of 6000 ft (*Traffic and Highway Engineering,* Nicholas J. Garber and Lester A. Hoel, 2010).

The presence of a climbing lane on a two-lane (single carriageway) section can reduce the number of catastrophic overtaking accidents that occur due to the presence of opposing vehicles. Such accidents normally involve high-speed head-on or run-off-the-road accident types. Hedman (1990) quotes a Swedish study which concluded that climbing lanes on rural two-lane roads reduced the total accident rate by an average on 25 %, 10 % to 20 % on moderate up-gradients (3 % to 4 %), and 20 % to 40% on steeper gradients. It was also observed that additional accident reduction can be obtained within a distance of about 1 km. beyond the climbing lane.

Harwood et al. (1988) quote a California study by Rinde (1977) at 23 sites in level, rolling, and mountainous terrain where accident rate reductions were found due to the passing lane installation of 11 % to 27 %, depending on road width. When the sites in mountainous terrain were excluded from the analysis, accident reductions of 42 % were found for the level terrain sites as well as for the rolling terrain sites *(Safety Standards for Road Design and Redesign:* SAFESTAR Final Report November, 2002*).* Climbing lanes must be considered for roads when present traffic volumes are greater than 400 ADT in Ethiopian road conditions. Thus the application of climbing lanes is limited particularly to trunk and link roads (ERA Geometric Design Manual, 2002).

Emergency Escape Ramps

Where long, descending gradients exist, the provision of an emergency escape ramp at an appropriate location is desirable for the purpose of stopping an out-of control vehicle away from the main traffic stream. Highway alignment, gradient, length, and descent speed contribute to the potential for out-of control vehicles. There are four emergency escape ramps types. These designs are sand pile; and arrester beds, classified by grade: descending grade, horizontal grade, and ascending grade. All function by application of the decelerating effect of loose material. Sand piles, composed of loose, dry sand dumped at the ramp site, are usually no more than 120 meters in length. The influence of gravity is dependent on the slope of the surface. The increase in rolling resistance is supplied by the loose sand. Deceleration characteristics of sand piles are usually severe and the sand can be affected by weather. Because of these characteristics, the sand pile is less desirable than the arrester bed. However, at locations where inadequate space exists for another type of ramp, the sand pile may be appropriate because of its compact dimensions.

The use of loose material in the arrester bed increases the rolling resistance to slow the vehicle. Descending ramps can be rather lengthy because gravitational effects are not acting to help reduce the speed of the vehicle. The preferred type of escape ramp is the ascending type with an arrester bed. Ramp installations of this type use gradient resistance to advantage, supplementing the effects of the aggregate in the arrester bed, and generally, reducing the length of ramp necessary to stop the vehicle. The loose material in the arresting bed increases the rolling resistance, and also serves to hold the vehicle in place on the ramp grade after it has come to a safe stop. Escape ramps are constructed adjacent to the carriageway and each one of the ramp types is applicable to a particular situation and must be compatible with location and topographic controls at possible sites (ERA Geometric Design Manual, 2002).

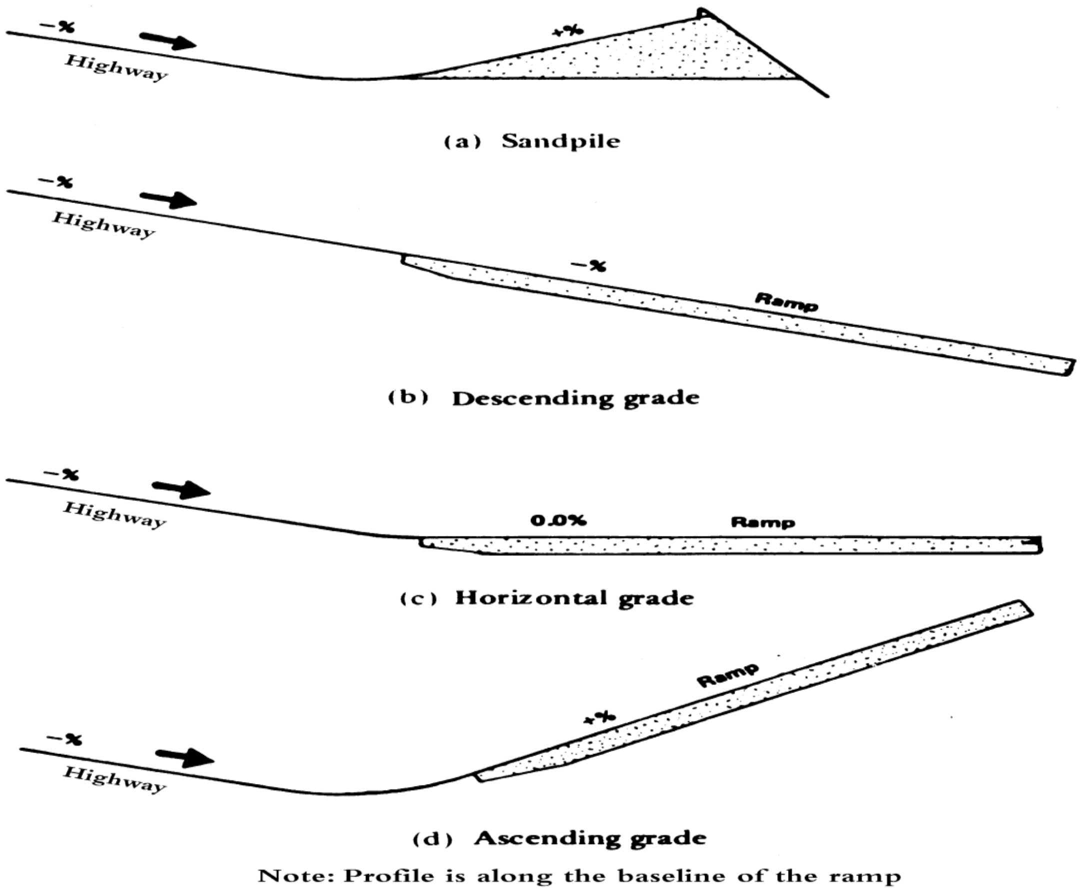


Figure 2.10: Types of Emergency Escape Ramps (Source: AASHTO)

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

To address the objectives stated in chapter one, the method applied to data collection, analysis, generation and interpretation of results; and finally with conclusions and recommendations as discussed below.

3.1. The Study Area

The study area is a road from Addis Ababa, station km 10+670 near Ayer Tena at the junction with the city's ring road up to Jimma city, station km 352+241 with a total length of about 341.571 km which is located in south-west direction found along the Trunk Road Addis-Metu numbered as A-5 by Ethiopian Roads Authority (ERA). The road is a two-lane two-way highway with a relatively highly trafficked route next to Addis-Adama outlet (from the five outlet road of the capital city of the country) and it is also the only means of land transport to connect south-western parts of the country to Addis Ababa.

From Addis Ababa (2,400 m above sea level), the road passes through densely-populated areas at Welete-suk (km 15), Alem Gena (km 19) and Sebeta (km 24) descending gently to the Awash flood-plain (km 44-52), at a mean sea level of 2,060 m. It crosses the Awash River at km 50 and passes through very flat, flat and rolling terrain, connecting the towns of Teji (km 55), Asgori (km 61), Tulu Bolo (km 81), Kora (km 93), Dilela (km 100) the road's highest elevation of 2,433m, Woliso (km 114), Gurura (km 127), Goro (km 134) and Wolkite (km 155).

At km 174, the road descends steeply to its lowest point of 1,088m at the Gibe River at (km 185.7). The road then rises steeply again to 1,670m at Abelti (km 199) and connects Kumbi (km 212), Natri (km 226), Saja (km 238), Sokoru (km 250), Deneba (km 265), Asendabo (km 285), Harer (km 295) and Serbo (km 318). The road enters Jimma at station km 351+841 and terminates at station km 352+241 (outside ECX compound at Jimma) at an altitude of 1,735m. Jimma is an important administrative zonal center and at the heart of the most productive coffee-growing area.

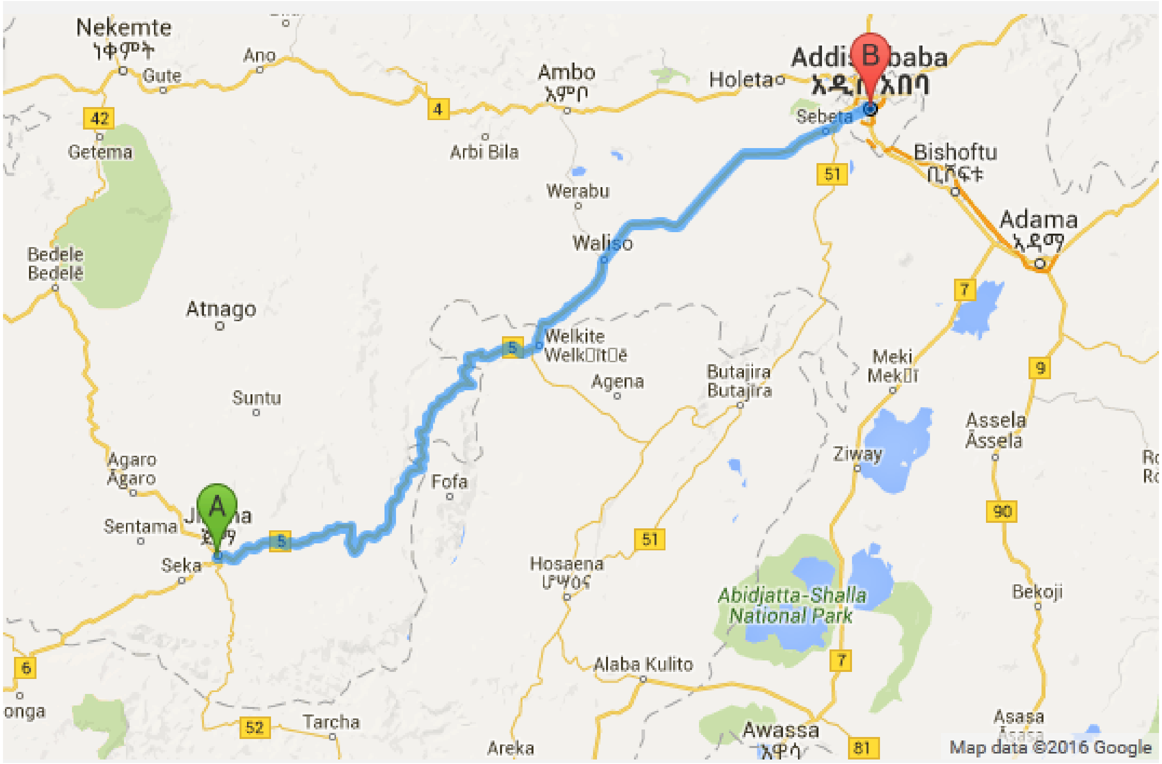


Figure 3.1 Map of Addis Ababa to Jimma Road

3.2. Research Design

The research can be categorized as analytical (explanatory), descriptive and applied type, because the research was initiated from practical problems and findings of whether there exists deficiencies of highway route location and geometric design attributes or not based on ERA geometric design standard and finally applied short-term and long-term engineering interventions were recommended through on site observations.

3.3. Study Variables

3.3.1. Dependent Variables

- Traffic accident;
- Highway drainage crossing structures re-location cost.

3.3.2. Independent Variables

- Horizontal alignment;
  - Curve radius
  - Length of tangent section
- Vertical Alignment
  - Grade
- Roadway cross-section;
- Traffic volume

3.4. Data Source and Research Population

To attain the stated objectives, previous research studies were reviewed that were found to be relevant to the objectives of this research. The literature review provided a broad background of the existing knowledge about route selection and geometric design deficiencies, road safety audit and insight into the problems encountered by the researchers at different stage of their works. The knowledge and experience gained during the study period were helped the writer of this research paper in developing reliable, efficient and effective study approach to focus on stated goals. During data collection process, types of gathered data were: existing road geometric design data of rehabilitation project, traffic accident and traffic count data, highway structures re-location/re-placement cost data and photos and videos of black spot areas.

3.4.1. Existing Road Geometric Design Data

The road factors being investigated in the geometric design includes horizontal curvature, roadway cross-section (carriageway, parking lane, shoulder, and footpath width) and vertical gradient of the road. The road data were available as softcopy of as-built design drawing of the road plan and profile as well as hardcopy of tender and final project report documents of Addis Ababa-Jimma Road Rehabilitation Project and were obtained from ERA, Jimma Road Network Management Directorate, ERA, Alemgena Road Network Management Directorate and ERA, Road Asset Management Coordination Directorate. These were substantiated through visual inspection, which was made on the road site.

3.4.2. Traffic Accident Data

Traffic crash data of five years, 2003-2007 E.F.Y which was used as a major input for the research analysis were collected from 11 Woredas and 3 City Administrations as well as 3 Zonal Police Offices found in Oromia and South Nations, Nationalities and People Regions.

3.4.3. Traffic Count Data

The traffic count data of five sections of the road, Addis-Alemgena, Alemgena-Woliso, Woliso-Wolkite, Wolkite-Gilgel gibe and Gilgel gibe-Jimma used during feasibility study of Addis Ababa Jimma Road Rehabilitation Project and recent traffic count data collected from three sections of the road, Addis Ababa-Woliso, Woliso-Wolkite and Wolkite-Jimma for the traffic year 2010 – 2014 G.C which were used for traffic volume capacity analysis of the road sections were obtained from ERA, Jimma Road Networking Management Directorate and ERA, Road Asset Management Directorate

3.4.4. Highway Structures Re-location/Re-placement Cost Data

Highway structures re-location/re-placement cost data of four years, 2012-2015 G.C fiscal year were obtained from ERA, Jimma Road Network Management Directorate and ERA, Alemgena Road Network Management Directorate.

3.4.5. Software, Spatial Data and Technical Support

ArcGIS desktop version 10 of the software including ArcMap, ArcCatalog and ArcToolbox was obtained from Environmental Systems Research Institute (ESRI). The Digital Elevation Model (DEM) of Ethiopia used for the generation of slope map and stream-Order map which is a major input for GIS based least cost path route selection was obtained from Diva-GIS which is distributed free of charge and is available for download from the website www.diva-gis.com. The DEM used were an SRTM spatial data which has a resolution of 1m at the equator, and was provided in 30 x 30 second tile size. Technical support for the analysis on using ArcGIS version 10 software was in majority of cases obtained from ArcGIS Desktop Help, consultations with GIS professionals and literature review. Some procedural errors could be also solved by web search and help of ESRI ArcGIS tutorials.

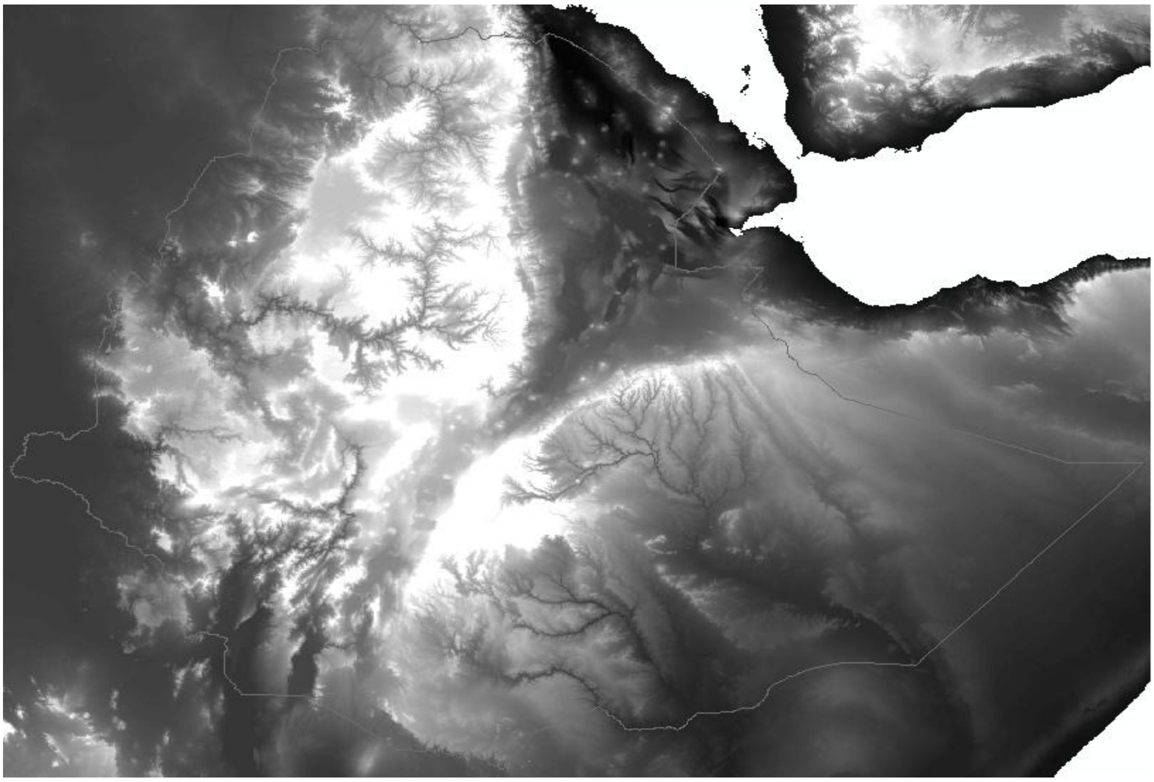


Figure 3.2: Digital Elevation Model of Ethiopia (Source: Diva-GIS)

3.5. Methods of Data Processing and Analysis

3.5.1 Route and Geometric Design Deficiencies Analysis

To achieve the objective of the research, the existing Addis Ababa-Jimma Road Rehabilitation Project hardcopy of Tender and Final Project Report as well as softcopy of as-built design and detail drawings (by using Auto CAD computer software) were analyzed whether complies with ERA and AASHTO Geometric Design standard or not. In addition to this, highway drainage crossing structures cost were analyzed by comparative study through dividing the existing highway route into three segment samples.

The traffic crash rate analysis on the road segment were done by dividing the highway route into four road segments by including as well as excluding Sebeta town in Addis-Woliso road segment. To identify the black-spot road segment on Addis-Jimma highway route, the formula used for the calculation of crash rate on the road segments were shown as below.

$$\mathbf{Rs} = \frac{N}{MVKT} \qquad\qquad \mathbf{MVKT} = \frac{V*L*n*365}{1{,}000{,}000}$$

Where, Rs = Segment crash rates

MVKT = Millions of Vehicles Kilometer Travel

N = Number of crashes at study location

L = Length of segment in Kms

V = Volume of traffic entering the segment in AADT

n = number of years in the study period

In this calculation, since both traffic crash and traffic volume data used were five years of the past, n is simplified to 1.

3.5.2 GIS Based Least Cost Path (Multi Criteria) Analysis

3.5.2.1 Method

For long-term interventions of option-2 (new route corridor selection), the geographic information system (GIS) software was used to perform the analysis. ArcGIS desktop from Environmental Systems Research Institute (ESRI), version 10 of the software including ArcMap, ArcCatalog and ArcToolbox was basically applied. Finally, part of tabular data preparation was done in the spreadsheet, MS Excel.

A. Slope Map from Digital Elevation Model (DEM)

The route should pass through smooth area as much as possible i.e. avoiding steep slopes, so as to decrease the need for cutting and filling during construction as well as to decrease operation and maintenance cost of vehicles after opening for traffic movement. Hence, slopes help to identify the maximum rate of change in surface value over a specific distance and they are expressed in degrees or percentage (in degrees, for the sake of this analysis). In actualizing the slope map from the DEM required for the least cost path analysis, the spatial analyst tool in ArcMap 10 was used in the slope map calculation. Calculate slope is one function of many in spatial analyst tool and this tool was used to derive the slope map from DEM.

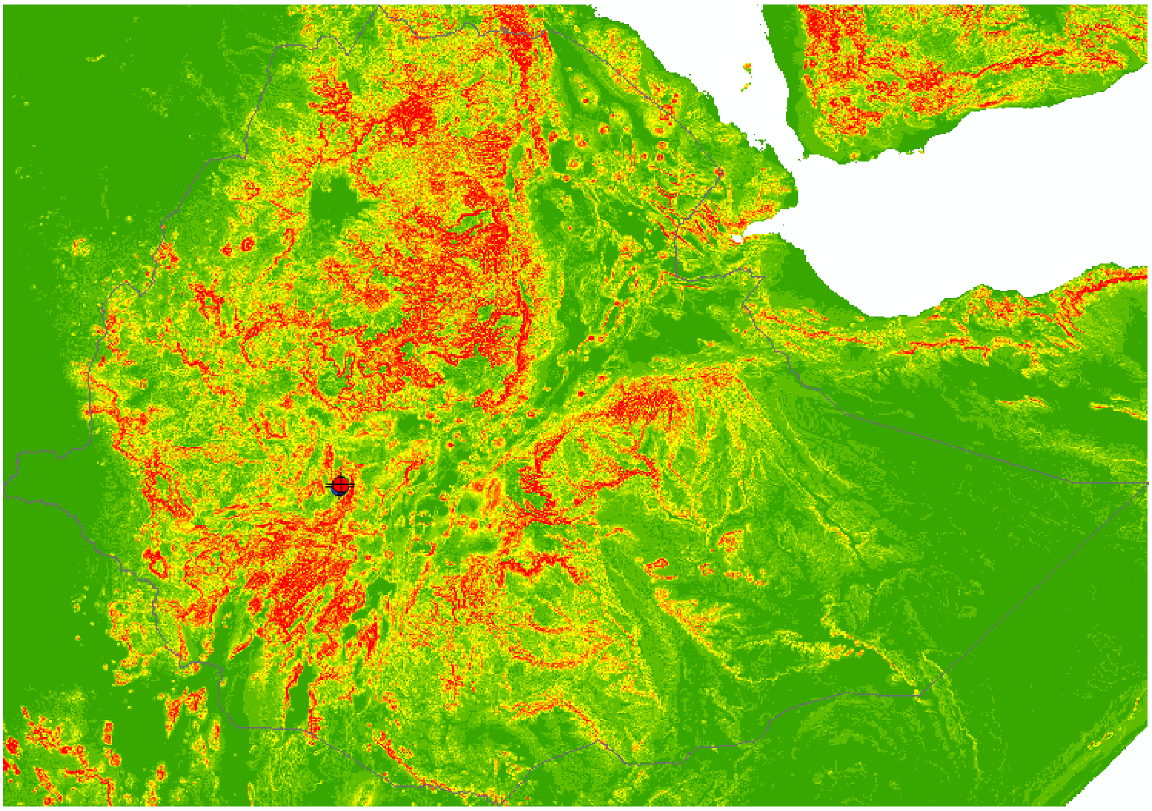


Figure 3.3: Slope Output Map Derived from DEM

B. Stream-Order Map from Digital Elevation Model (DEM)

The route should also intersect with minimum number of water features, or streams with minimum sizes as much as possible. Hence stream ordering is used to differentiate streams having different sizes in different basins over the area of study. The Stream-order raster used for the final thesis analysis was also derived from the Digital Elevation Model (DEM) of Ethiopia and the analysis was carried out for the whole basins found in Ethiopia. In this analysis, the spatial analyst tools in ArcMap 10 named as Fill, Flow direction, Flow accumulation, Con, Stream order and Raster to Polyline tools were used in the stream order analysis. As the result of software analysis based on ArcGIS 10 done by Strahler method, stream order raster having a Grid-code of 9 was derived.

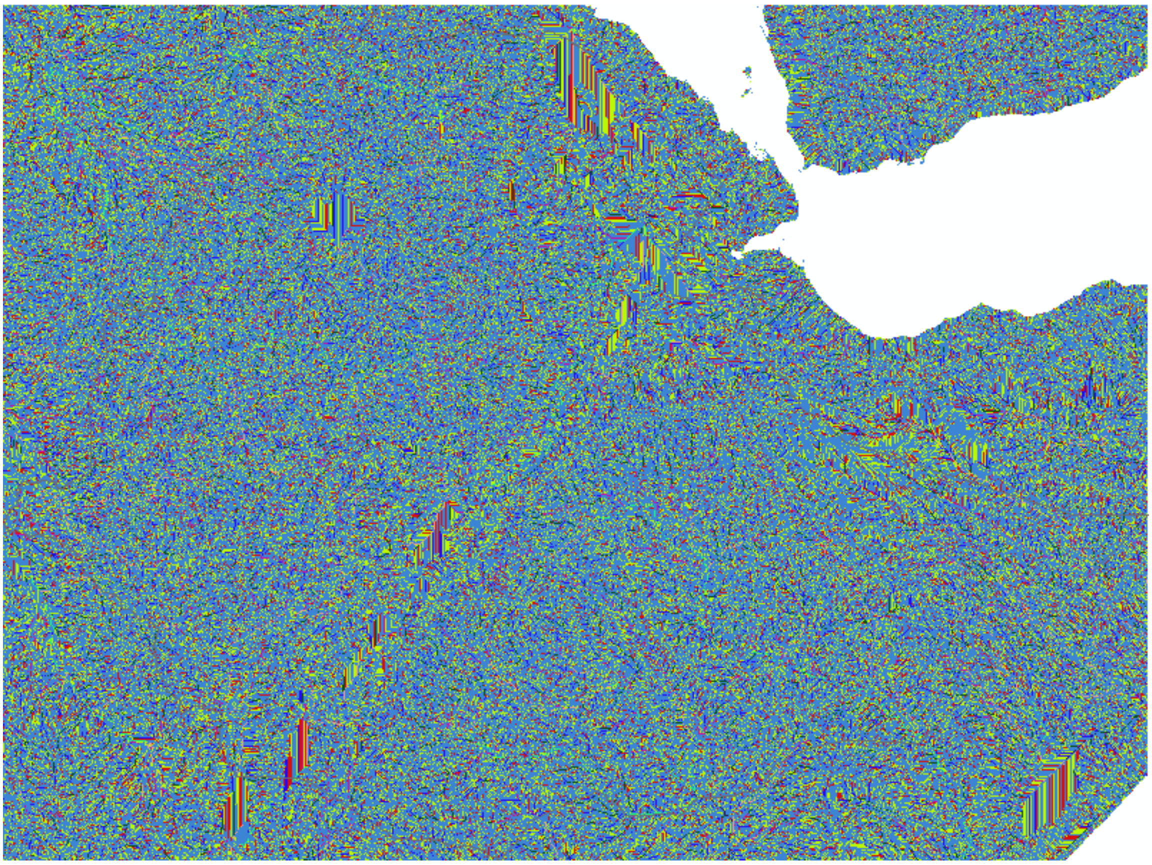


Figure 3.4: Stream-Order Output Map Derived from DEM

C. Creating Start and Destination Point of Road Path

To compute a distance over a rough or friction surface, there is a need to specify the start and destination points in which the path is to follow. The source feature is the image that indicates the cells from which cost should be determined, which is an integer with cells indicated by a zero value. Two new shape files, the start and destination points for the road path were simply created by inserting their geographic coordinates (latitude and longitude) in new shape file dialog box using ArcCatalog 10 and the cost path in the distance menu in the cost dialogue box was used in the calculation. This start and destination points were not created as stand-alone points. This was to ensure that the route points created was within the coordinates of the area under study. The blue and red spots in Figure 3.5 show the start point and destination points of the road path in the Ethiopian boundary.

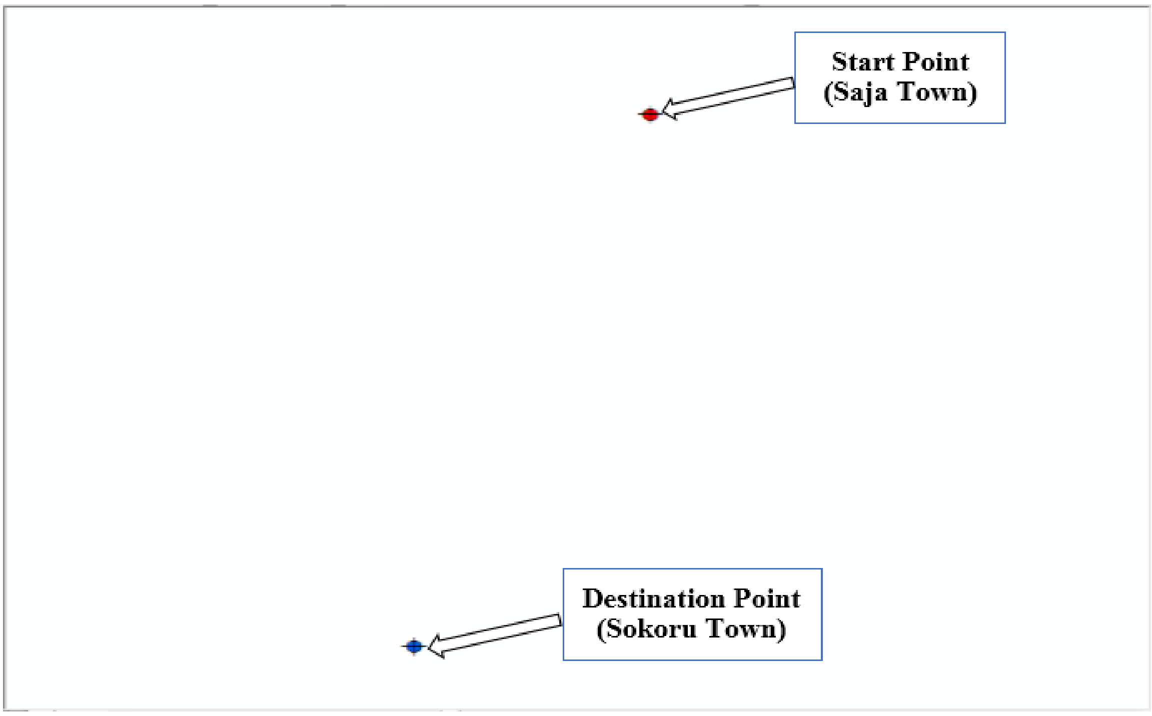


Figure 3.5: Map Showing Start and End Points for the Road Path

3.5.2.2 Model Creation

After the data preparation, the next step is the creation of the model. The creation of the model requires a spatial analysis toolbox in ArcGIS which is a comprehensive tool for GIS analysis. The created model helps to derive information from the available data used in identifying spatial relationship, finding suitable locations and the calculation of the accumulated cost of traveling from one point to another. In creating the model, a new toolbox was created below the toolboxes and from the toolbox, a new model was created. The properties needed (Same as Ethiopian Boundary & Same as Layer Elevation) were entered in the model properties and this helps to describe what the model is to be used for.

In the case of this thesis, the model is to be used to find the best route for a new alternative road between Gibe bridge-Abelti town, Saja town-Sokoru town and Gibe Bridge-Deneba town based on a reclassed slope map and a stream order map. Control points through which the alignment has to pass may cause alignment to often deviate from the shortest or easiest path. In weighted overlay table the scale value, 1 was used to represent good areas of lesser slope and smaller drainage crossings with low cost value to build a road while 10 represent bad areas of higher slope and bigger drainage crossings, which is a high cost to build a road. Figure shows the created model. The blue boxes in the model are used to represent maps that must exist before the analysis while the yellow and green boxes are the functions and intermediate maps and end results (Fig 3.6 & 3.7).

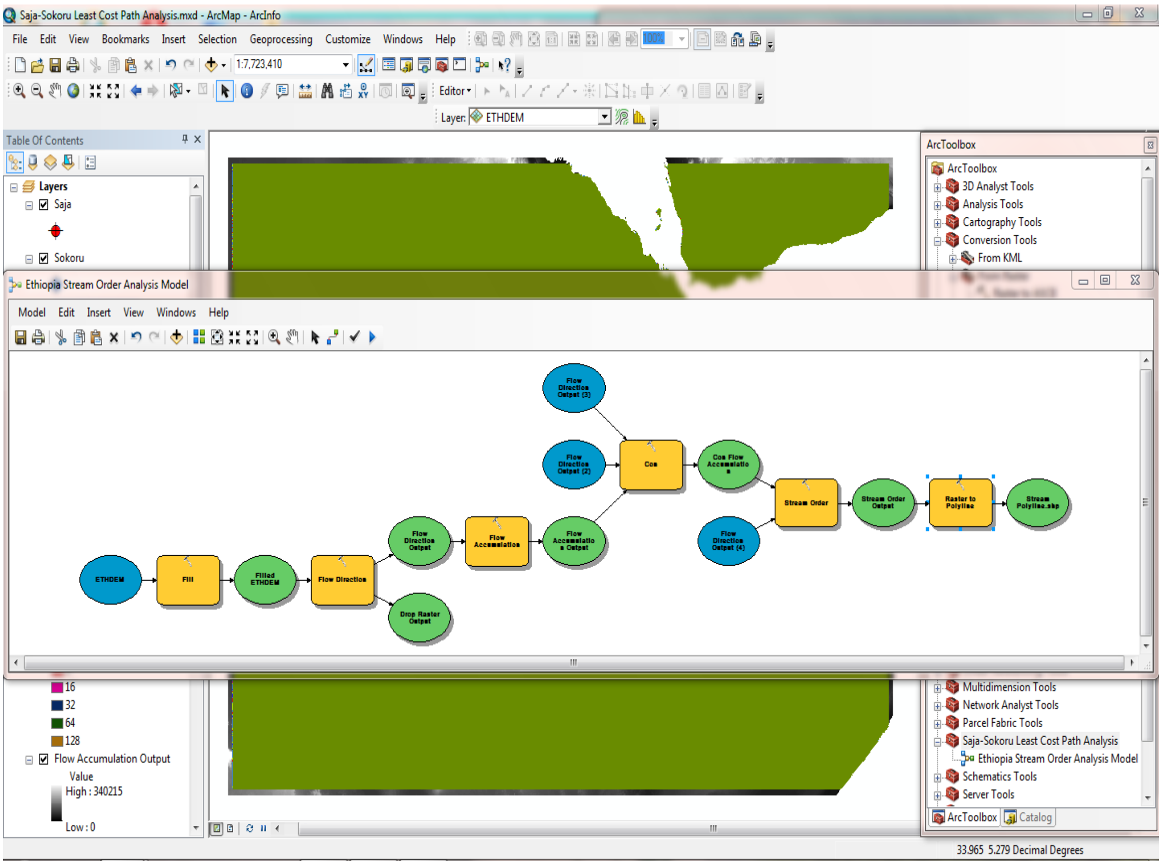


Figure 3.6: Stream-order Analysis Model

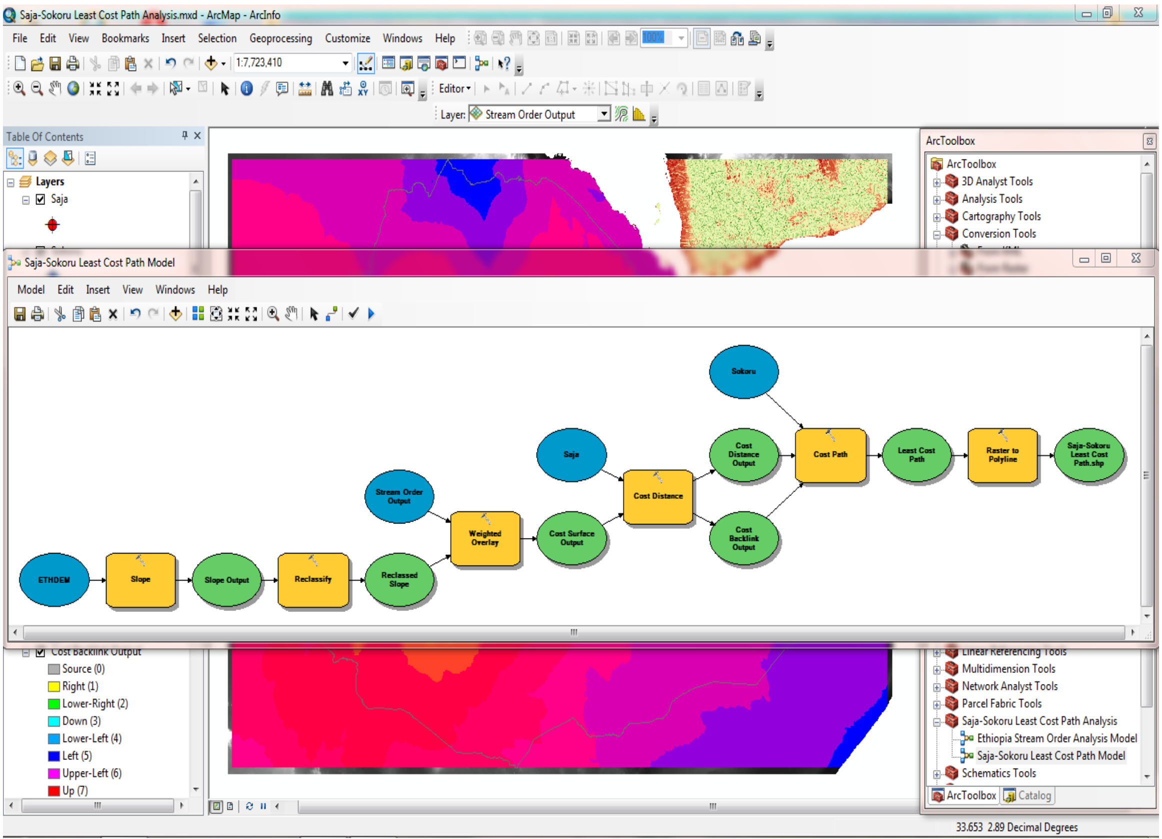


Figure 3.7: Saja-Sokoru Least Cost Path Analysis Model

A. Reclassed Slope Map

The slope map was reclassified into a relative friction (rough or unlevelled surface) cost of 10 classes in order to have a common value. The slope map classification was achieved using symbology under the diagram properties in the model. In the classified slope map, 1 was used to represent good areas with low cost value to build a road while 10 represent bad, which is a high cost to build a road. The reclassification of the slope map will help in differentiating the different slopes between the different slope classes during criteria evaluation and as such provides a proximity surface on the best area to construct the road.

Table 3.1: Reclassification of Slope Map in Degrees

Old Values (Slope in Degrees)	New Values Rank
0-2	1
2-3	2
3-4	3
4-5	4
5-6	5
6-7	6
7-9	7
9-12	8
12-16	9
16-82.275467	10

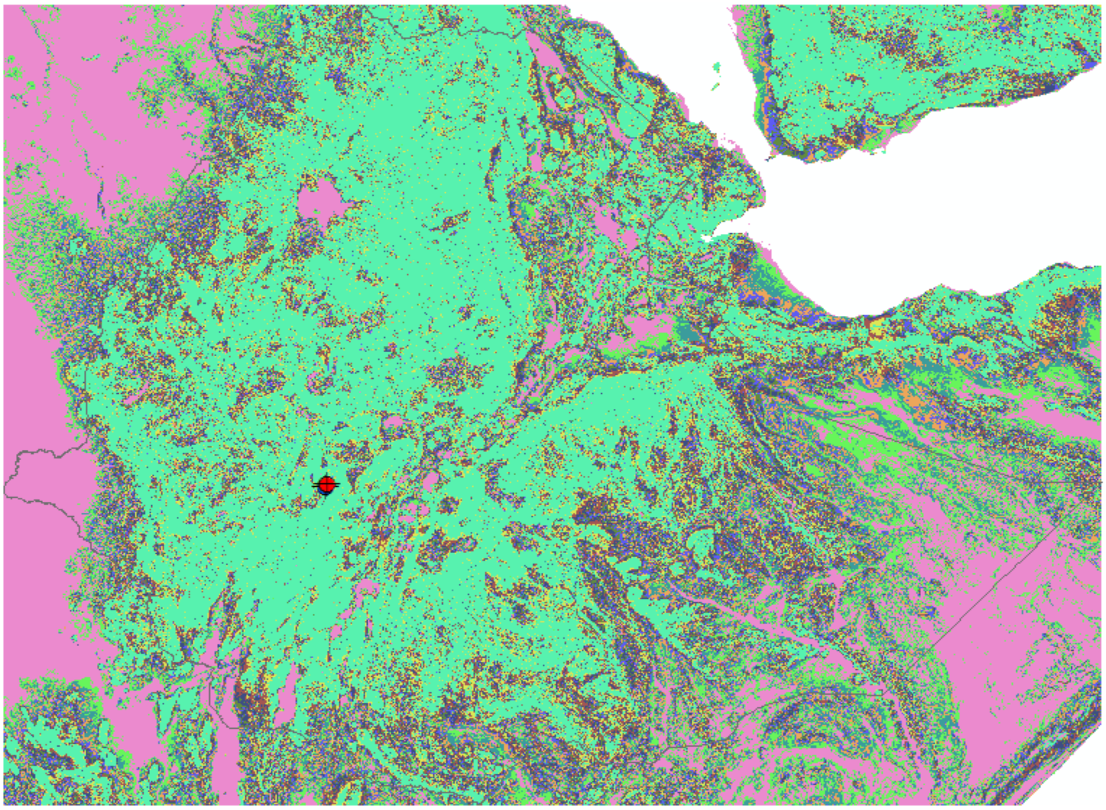


Figure 3.8: Reclassed Slope Map

B. Weighting of Reclassed Slope and Stream-Order

Two maps have been produced in the model namely Reclassed slope and Stream-order output from Digital Elevation Model (DEM). To ensure that both maps are of the same classes, the stream-order map containing the relative weights was reclassified into 10 classes. After the determination of comparative weight of parameters, the derived weights were manually inserted in the weighted overlay table under the scale value. These derived weights helps to identify area of agreement that is appropriate for routing a road path at each map location. The two maps were combined into one total map named as cost surface output map. In this case the influence factor given for Reclassed slope was considered to be 0.6 (60%) while for stream-order was 0.4 (40%) as shown in Table 3.2.

Table 3.2: Weighted Overlay of Reclassed Slope and Stream-Order Output

Raster Type	Influence %	Field Name	Scale Value
Reclassed Slope Output	60	Value	-
		1	1
		2	2
		3	3
		4	4
		5	5
		6	6
		7	7
		8	8
		9	9
		10	10
Stream-Order Output	40	Value	-
		1	1
		2	3
		3	5
		4	7
		5	9
		6	10
		7	10
		8	10
		9	10
Sum of Influence	**100**		

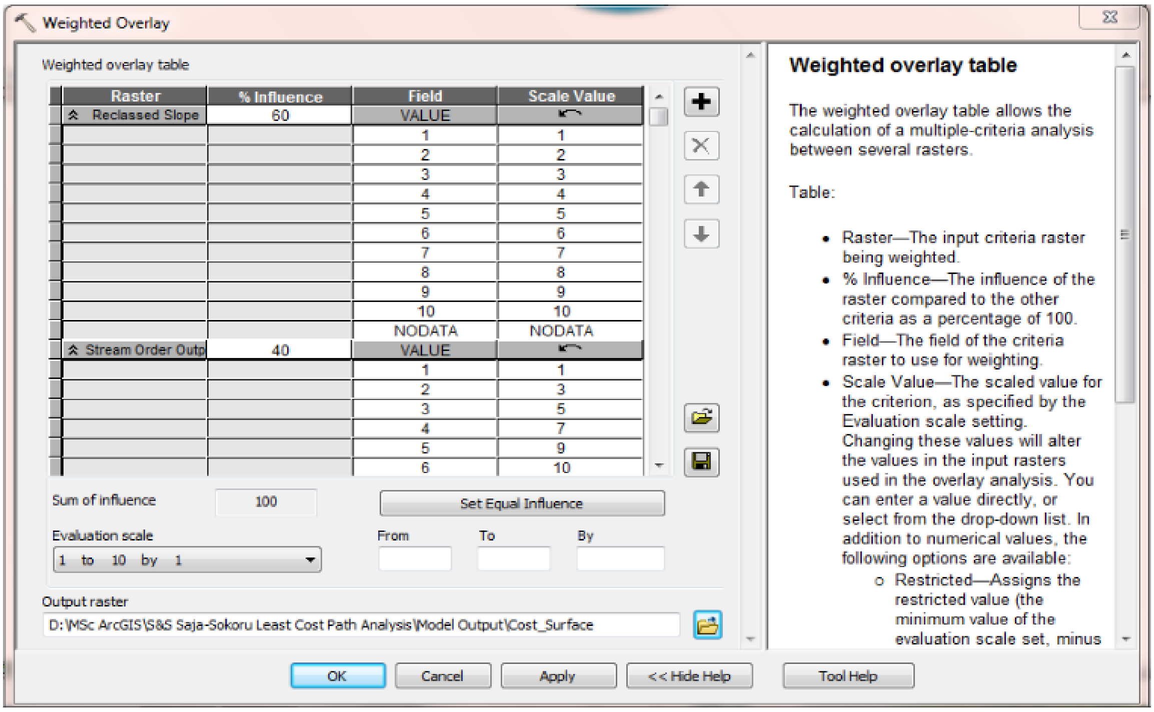


Figure 3.9: Weighting of Reclassed Slope and Stream-Order

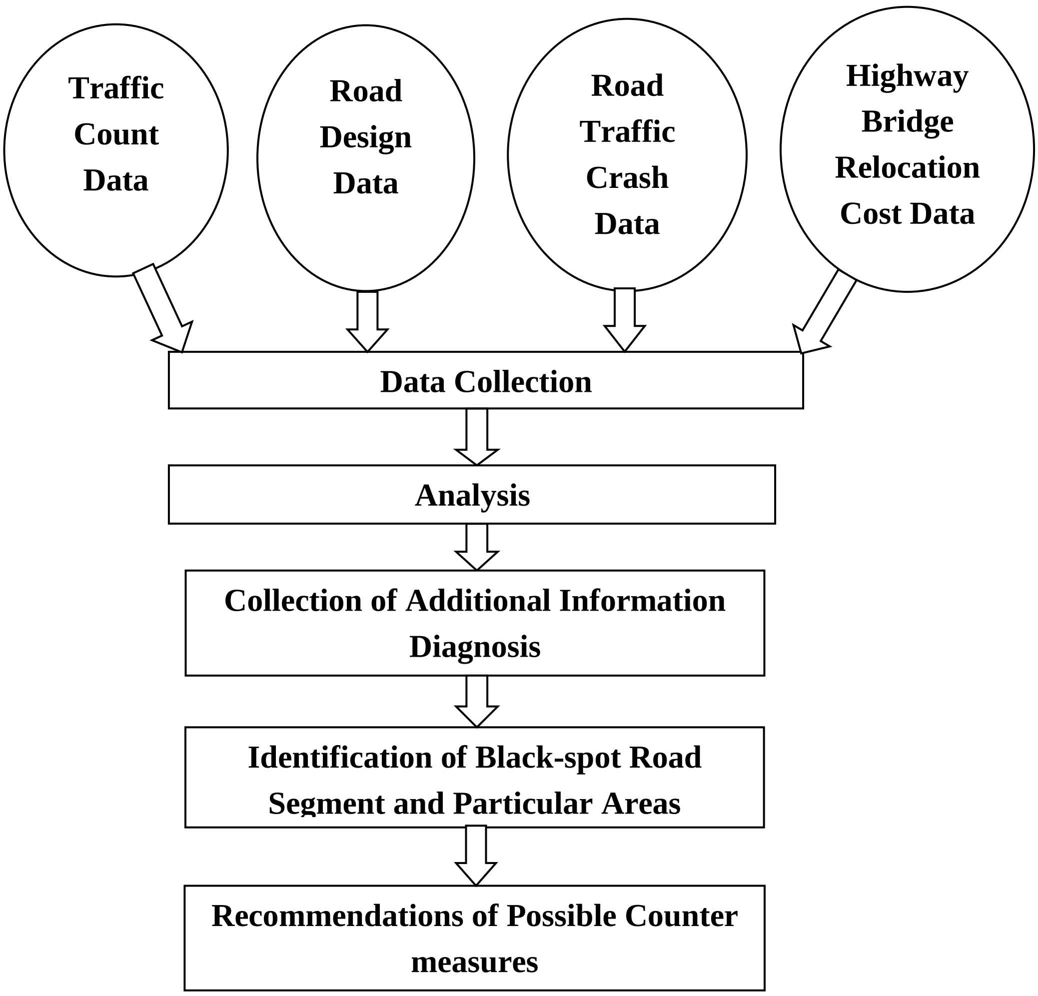


Figure 3.10: Flow Chart of Major Activities Carried out During the Research Work

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Route and Geometric Design Deficiencies on Addis-Jimma Road

To address the aim of the research paper, all the collected data were checked on site with the help of traffic polices through field trips and analyzed for its sufficiency or deficiency of geometric design attributes of that particular site and road segment in accordance with ERA and AASHTO geometric design standards by using softcopy of existing as-built design and the recent overlay design drawing, hardcopy of tender and final project report of Addis Ababa-Jimma Road Rehabilitation Project. Finally, possible and alternative countermeasures decided were conducted through results and discussions as stated below.

4.1.1 Addis Ababa (Km 10+670) to Gibe Bridge (185+700)

Cross-Sections

A. Addis Ababa (Ayer Tena) km 10+670 to km 28+800 Sebeta (Dima)

According to Addis Ababa to Jimma Road Rehabilitation Project Final Project Report, in general the design took cognizance of the town sections as proposed by Pietrangeli during feasibility study. In view of the very high cost of providing them and ERA's desire to minimize costs wherever possible, some sections were reduced or modified. In many instances the full town sections with parking lanes and shoulders were reduced in length because they would cover large areas with very little or no commercial activity. Instead, wider shoulders or sidewalks were introduced in many of the longer town sections because this was considered to be sufficient for the pedestrian and animal traffic. Based on As-built design document of Addis-Jimma road, the town sections from Ayer Tena to Sebeta (Dima) provided with parking lanes are as listed in Table 4.2.

Average of LHS and RHS lane length = (3842+4170)/2 = 4006 m (4km)

Table 4.1: Traffic Volume during Feasibility Study on Addis Ababa-Jimma Road

Road Section Name	Road Section In (km)	Traffic Volume in Terms of AADT Projected upto 2020 G.C
Addis-Alemgena	10+760 – 19+000	3500
Alemgena-Woliso	19+000 – 114+000	1200
Woliso-Wolkite	114+000 – 155+000	1500
Wolkite-G/Gibe	155+000 – 290+300	800
Gilgel Gibe-Jimma	290+300 – 336+400	900

Table 4.2: Sections of Ayer Tena to Sebeta (Dima) Provided with Parking Lane

Chainage	Carriage Way	Parking Lane Width (m)			
		LHS	Length (m)	RHS	Length (m)
10+670-11+000	3.50	3.50	330.00	3.50	330.00
11+020-11+040	3.50	-	-	3.50	20.00
11+140-11+180	3.50	3.50	40.00	3.50	40.00
11+460-11+520	3.50	3.50	60.00	3.50	60.00
11+540-11+580	3.50	-	-	3.50	40.00
11+600-11+660	3.50	-	-	3.50	60.00
11+920-12+140	3.50	3.50	220	3.50	220.00
12+400-12+540	3.50	3.50	140.00	3.50	140.00
12+560-12+740	3.5	3.50	180.00	3.50	180.00
13+620-13+680	3.50	5.00	60.00	-	60.00
13700-13+820	3.50	5.00	120.00	-	120.00
14+080-14+540	3.50	3.50	460.00	3.50	460.00
14+820-15+180	3.50	3.50	360.00	3.50	360.00
18+420-18+480	3.50	5.00	60.00	-	-
18+500-18+580	3.50	5.00	80.00	3.50	80.00
18+600-18+820	3.50	3.50	220.00	3.50	220.00
19+080-19+500	3.50	3.50	420.00	3.50	420.00
20+220-20+320	3.50	3.50	100.00	3.50	100.00
23+320-23+380	3.50	3.50	60.00	-	-
23+400-23+780	3.50	3.50	380.00	3.50	380.00
23+800-24+020	3.50	3.50	220.00	3.50	220.00
24+040-24+160	3.50	3.50	12.00	3.50	120.00
24+180-24+660	3.50	3.50	480.00	3.50	480.00
24+680-24+740	3.50	3.50	60.00	3.50	60.00
Total			**3842.00m**		**4170.00m**

However, from the town section where Addis-Jimma road rehabilitation works commenced at Ayer Tena (km 10+670), the road passes through densely populated, highly trafficked and under fast growing town sections of Welete Suk (km 15), Alem Gena (km 19), and end of Sebeta Town at Dima (km 28+800) which are currently fully integrated with Addis Ababa and accommodating high traffic flow from additional route of Alem Gena-Sodo road. In contrast to this, from the total length of 18.13 km of the town section from Ayer Tena to Sebeta (Dima), only 4 km (22.1 %) of the town section is provided with parking lane. The remaining 14.13 km (77.9 %) of the town section instead provided with 1.5-2.5m wide shoulder or 2.5m wide Pedestrian walkway since it was considered as a rural area with very little or no commercial activity at the time of feasibility study in 1995 G.C. During feasibility study, the traffic volume forecasted in terms of AADT projected up to the year 2020 G.C were summarized as in the Table 4.1.

Hence, at the time when the feasibility study was carried out, the section of the road from Addis Ababa upto Wolkite were designed as DS3 since the traffic volume forecasted in terms of AADT upto the year 2020 G.C for the design period of 25 years were 3,500 for Addis-Alemgena, 1,200 for Alem Gena-Woliso and 1,500 for Woliso-Wolkite road segments. However, surprisingly, the traffic volume on Addis Ababa – Woliso (Ghion) road segment in terms of AADT had reached 5,140 in the traffic year 2014 G.C. This condition indicates that the road section has accomplished its service life (regarding to traffic volume accommodation capacity) before end of its design period in 2020 G.C.

Table 4.3: Road Users Injured By Traffic Accident in Sebeta City 2003-2007 E.C

	Fatal Injury		Heavy Injury		Slight Injury		Total
Victims	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
Drivers	11	-	8	-	2	-	21
Pedestrians	47	17	76	21	75	37	273
Passengers	7	2	40	15	61	24	149
Total	**65**	**19**	**124**	**36**	**138**	**61**	**443**

In addition to this, the full town section of the road was constructed without median island which can be used as a refugee area during sudden accident case for the pedestrians crossing the road and abrupt or isolated changes in cross-section of the road resulting high speed of vehicles released from congested or bottle-necked part of the road section, hence the drivers are moving faster in the wider section of the road for the reason to compensate the wasted time. Based on the traffic count data obtained from ERA, Road Asset Management Coordination Directorate, the recent traffic volume of five years, 2010-2014 G.C are summarized as in Table 4.4.

As the matter of this, severe traffic accident especially in relation with Vehicle – Pedestrian collisions, 273 (61.63 %) from the total of 443 which were occurred between fiscal year of 2003 – 2007 within five years in the town section of Sebeta, on Addis – Jimma road (Table 4.3) due to high speed of vehicles resulting from the roadway cross-section problem in addition to the drivers (especially younger drivers) inability to judge speeds accurately and pedestrians poor road usage behavior.

This condition indicates that the highly trafficked and the 2nd busiest road section in Sebeta town, cannot accommodate the current traffic flow. Hence, the road segment in town sections from Addis Ababa (Ayer Tena) km 10+670 to km 28+800 Sebeta (Dima) should be widened uniformly as the town section of DS2:

- Carriageway = 3.65m (single lane);
- Parking lane = 3.5 (on both sides);
- Footway = 2.5 (on both sides);
- Median barrier should be provided between traffic lanes.

Or it could be upgraded to DS1 based on further projection of traffic count for the design period to be intended.

Table 4.4: AADT by Road Section in Traffic Year 2010 G.C – 2014 G.C.

Traffic Year (G.C)	Road No	Route No	Route Name	Length (km)	Total of Vehicle Composition
2010	7	1	Addis Ababa – Woliso	116	2,993
		2	Woliso – Wolkite	42	1,568
		3	Wolkite – Jimma	188	910
			Total Length of the Road	346	
2011	7	1	Addis Ababa – Woliso	116	3,959
		2	Woliso – Wolkite	42	2,291
		3	Wolkite – Jimma	188	1,006
			Total Length of the Road	346	
2012	7	1	Addis Ababa – Woliso	116	2,943
		2	Woliso – Wolkite	42	1,998
		3	Wolkite – Jimma	188	1,293
			Total Length of the Road	346	
2013	7	1	Addis Ababa – Woliso	116	4,164
		2	Woliso – Wolkite	42	1,818
		3	Wolkite – Jimma	188	1,125
			Total Length of the Road	346	
2014	7	1	Addis Ababa – Woliso	116	5,140
		2	Woliso – Wolkite	42	2,205
		3	Wolkite – Jimma	188	1,453
Total Length of the Road				**346**	

B. Town Sections on Addis to Gibe Bridge Road Segment (Excluding Sebeta)

On the road segment from Addis to Gibe Bridge, the roadway cross-sections in the towns of Tefki, Teji, Asgori, Tulu Bolo, Dilela, Woliso, Gurura, Goro and Wolkite has similar Carriageway width of 7m and Parking lane width of 3.5m on both sides, totally 14m without the presence of median barrier since it was designed as DS3. However, in many instances the full town sections with parking lanes and shoulders were reduced in length for the reason they would cover large areas with very little or no commercial activity, instead wider shoulders or sidewalks were introduced in many of the longer town sections because this was considered to be sufficient for the pedestrian and animal traffic. In some cases small town sections were reduced to bus stops on both sides of the road because this was the only apparent need in the area.

However, part of the town sections by the time which were considered as with very little or no commercial activity are currently fall into center of the towns. This abrupt changes of cross-section in parts of the towns, in turn creates safety risks. Since, as the villages and towns along the road have a speed limit of 30 km/hr while the speed limits of two-lane paved rural road along the road is 80km/hr-100km/hr, most drivers (especially youngers) are operate at a higher speed through agricultural and open areas with limited distant sight obstructions, entering the towns abruptly without sufficient reduction of speed due to the lack of transitional speed zones and inability to judge speeds accurately in addition to pedestrians poor usage behavior of the road.

As the matter of this, traffic accidents mostly related with vehicle-pedestrian collisions resulting significant human life loss and considerable property damages on the road users where the road in these towns section with relatively lesser alignment problem.
Hence, in order to alleviate these problems,

- ☞ In the long-term interventions, the road in the town sections of Tefki, Teji, Asgori, Tulu Bolo, Dilela and Woliso should be provided with parking lanes for the full length of the towns section and median island as DS2 of town sections since the traffic volume in terms of AADT in Addis-Woliso road section had reached 4,164 in 2013 and 5,140 in 2014 G.C traffic year which has increasing in surprising manner.
- ☞ In order to create psychological readiness for speed reduction on the drivers, transitional speed limit zones should be adopted on the road approaches to these towns before the drivers entering the towns with 30km/hr of speed.
- ☞ Strict enforcement of speed limit control by using devices such as handheld portable or vehicle mounted radar on the road approaches to these towns.

Or it could be upgraded to DS1 based on further projection of traffic count for the design period to be intended

Rural Sections

Apart from the town sections, which were defined on the "List of Typical Cross – Section", the carriageway and shoulder widths from the start of Addis Ababa (Ayer Tena) to Jimma City were as shown in Table 4.5.

Table 4.5: List of Typical Cross-sections of Existing Addis Ababa-Jimma Road in Rural Sections

Station in Km	Chainage (Km)	Carriageway Width (m)	Shoulder Width (m)
10+670-118+000	107.33	3.50	1.50
118+000-173+000	55	3.50	1.00
173+000-193+245	20.25	3.25	1.00
193+245-198+400	5.16	3.00	1.00
198+400-268+954	70.55	3.25	1.00
268+954-302+170	33.22	3.50	1.50
302+170-352+241	50.1	3.50	1.00

C. Sebeta (Dima) to Woliso (Rural Section)

Km 28+800 to km 118+000 Carriageway width = 3.50m, Shoulder width = 1.50m

During feasibility study, the traffic volume on Addis Ababa-Alem Gena road segment projected in terms of AADT were 3500 and Alem Gena-Woliso (Ghion) were 1200 upto the year 2020 G.C for the design period of 25 years. However, the design life of the road segment has currently out dated regarding to the traffic volume accommodation capacity, since the traffic count on the road segment in terms of AADT had reached 5,140 in the traffic year 2014 G.C, which is surprisingly in an increasing manner as shown in the Table 4.4.

Despite this, Sebeta (Dima) to Woliso road segment has been currently accommodating high traffic volume next to Addis-Adama outlet (from the five outlet road of Addis). In addition to this, intensive non-motor vehicles, pedestrians and animals using the road sections are forced to moving on the carriageway rather than using a narrow shoulder (1.5m) especially during major market day. In order to accommodate the traffic volume under fast growing and to encourage the intensive non- motor vehicles and pedestrians to walk on the shoulder rather than using the traffic lane, the cross-section of the road should be widened as DS2.

Hence, from station km 28+800 to km118+000 (89.2km) the roadway width should be widened to:

- Carriageway width = 3.65m
- Shoulder width = 3.0 m

Or it could be upgraded to DS1 based on further projection of traffic count for the design period to be intended.

D. Woliso to Gibe Bridge (Rural Section)

During feasibility study, the traffic volume forecasted in terms of AADT upto 2020 G.C for the design life of 25 years on Woliso-Wolkite road section were 1,500, which were designed as DS3 (i.e. Carriageway width = 7m and shoulder width = 1.5 -3.0 m) since the road segment passes through flat to rolling terrain. However, as listed in Table 4.5 "List of Typical Cross – Section" data, from station km 118+000 to km 173+000, the width of the shoulder provided at the time was 1.0 m and from station Km 173+000 to km 185+700 the carriageway width was 6.5m which are apart from the current ERA Geometric Design Standard.

Despite this, the recent traffic volume in terms of AADT in the traffic year 2014 G.C on this road segment is 2,205 for Woliso-Wolkite and 1,453 for Wolkite-Jimma (Table 4.4) which are still in between 1000-5000 (DS3) as during the feasibility study. However, since the road segment is traverses through gently undulating terrain up to station Km 173+000 with limited distant sight obstructions, drivers are tends to moving their vehicles faster in irresponsible and unsafe manner even through escarpment of Gibe Valley without reduction of vehicle speed, and hence considerable traffic accident occurrence has been observed along the road segment resulting loss of human life and property damages. To encourage non-motor vehicles, pedestrians and animals to move on the shoulder rather than using the carriageway, the roadway cross-section should be widened as DS3.

Hence, the cross-section of the roadway should be uniformly widened to

- Carriageway = 7m, Shoulder = 1.5m – 3.0m, as the availability of road right of way (for AADT 1000 – 5000 and flat and rolling terrain)

Or it could be upgraded to DS2 based on further projection of traffic count for the design period to be intended.

Horizontal Alignment

Addis Ababa (Km 10+670) – Gibe River Bridge (Km 185+700)

Based on the analysis of as-built design drawing softcopy of AutoCAD and as summarized in Table 4.7, the concentration of horizontal curves in these road segment comprises 0.75/km that is less than 1 curve per 1km of road length. There is no horizontal curves having radii below 40m and 90.1% of the horizontal curves existed on this road segment have curve radii above 125m. From the total length (175.03 km) of the road section, the curve length accounts 27.48 km (15.7%) while the tangent (straight) sections accounts 147.55 km (84.3%). When comparing the deficiencies on horizontal alignment of this road section with Gibe Bridge to Deneba road segment, it is quite contrast.

However, when we approach from Addis at km 146, the old narrow Rebu river bridge (6m width) which was constructed by Italians before 70 years for the intended carriageway width of 6m at that time, which is lesser than the current 7m carriageway width of the approach road and constructed in broken-back horizontal curves having a radius of 165m and 100m in correspondence with 4.106 % grade in descending and 3.867 % grade in ascending direction which is considered as a particular black-spot area causing severe traffic crash resulting human life lose and property damages, since drivers do not generally anticipate successive curves in the same direction and sag vertical curves in addition to abrupt changes in cross-section of 7m road to 6m bridge. Hence, currently it cannot accommodate large size Truck-trailers safely in addition to the alignment problem.

Table 4.6: Tangent Sections above 4km Length on Addis to Gibe Road Segment

Station in km	**Tangent Length in km**
28+590 to 32+980	4.39
41+080 to 48+860	7.78
60+000 to 82+190	22.19
95+847 to 100+090	4.243
152+000 to 163+091	11.09

In addition to this, the length of the tangent sections of some horizontal curves found on the road segment listed in the Table 4.6 are above 4km, which is departure from ERA geometric design standards. Since long tangent sections of horizontal curves increase the danger from headlight glare at night, create fatigue on drivers and usually lead to excessive speeding which is the major cause of traffic crashes. Hence, in addition to narrow bridge, carriageway and shoulder width problem, long tangent sections and maintenance of uneven overlay of asphalt concrete has causing traffic accident resulting huge human life loss and considerable property damages.

Hence, to alleviate the problems stated above, in the long-term interventions:

- ☞ Long tangent sections of the road stations listed above should be provided at appropriate distance with Road hump or Rumble strips painted white (preferably reflectorized) to make them visible at night, and road signs should also be placed to forewarn the drivers.
- ☞ Rebu Bridge should be re-located on the upstream side in order to avoid the broken-back curves and simultaneously to widen the cross-section of the bridge.

Table 4.7: Category of Horizontal Curve Radius on Existing Addis-Jimma Road

Section of The Road	Chainage (km)	Category of Horizontal Curve Radius in meters									
		0 to 20	21 to 84	85 to 124	125 to 174	175 to 200	201 to 274	275 to 394	395 to 629	630 & above	Total No Curves
Addis-Gibe	175.03	-	3	10	9	16	16	18	19	40	131
Gibe-Deneba	80.3	7	192	112	65	29	31	41	29	47	553
Deneba-Jimma	86.24	-	4	30	20	16	16	41	37	31	195

Vertical Alignment

Addis Ababa (Km 10+670) – Gibe River Bridge (Km 185+700)

Based on the analysis of As-built design drawing and as summarized in Table 4.8, on Addis Ababa-Gibe Bridge road segment 82.4% of the vertical gradient fall into the category of 0% - 3% grade and 12.2% fall into 3%-5%, which means 94.42% of the road segment gradient fall into 0%-5% grade. The average grade is 1.5% and the maximum grade is 8.087% which is found near Gibe Bridge. In general, when comparing the deficiency on vertical alignment with Gibe Bridge to Deneba road section it is quite different.

Table 4.8: Category of Vertical Gradient on Existing Addis Ababa Jimma Road

	Vertical Gradient in %								Average Grade (%)	Max Grade (%)	Min Grade (%)
Road Segment	**0-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**			
Addis-Gibe	82.4	7.1	4.9	3.7	1.2	0.5	0.1	-	1.5	8.087	0
Gibe-Deneba	33	10.6	15.1	18.8	15.6	5.4	1.5	0.2	4.13	9.65	0.01
Deneba-Jimma	64.7	12.2	11	8.2	2.6	1	0.2	-	2.45	8.31	0

However, the road section passes through the escarpment of Gibe valley, from station km 174+000 to km 185+700 where the maximum of 8.087% grade is found and 42.61% of the vertical alignment fall into the category of 5%-9% grade, there is a noticeable traffic accident occurrence resulting significant human life loss and property damages since the drivers do not anticipate with abrupt changes of geometric characteristics of the road especially for those new for the route.

Even though, the research paper aimed to investigate effects of route and geometric design deficiencies on the road users, in addition to the above stated problems associated with geometric design attributes, the road segment (especially between station km 28+800 to 80+000) mostly traverses the natural ground conditions comprise exclusively black cotton soils in very flat and poorly drained areas which is the major cause of the longitudinal (at center and edge) and transverse cracking on asphalt concrete pavement on this road section.

To alleviate this problem, ERA's road maintenance teams usually carried out maintenance of asphalt overlay by removing only the cracked part of the road in uneven manner over the intensive part of the road and hence it creates defects of unevenness and profile on asphalt concrete pavement lead to jumping of vehicles and may cause loss of control (especially for two wheelers) which in turn resulting run-off-the-road/run-off-the-lane, rollover, collisions with other motor and non-motor vehicles, road side objects, pedestrians and animals walking on the shoulder.

Hence, to alleviate the traffic crash associated with vertical alignment deficiencies on this road segment:

- ☞ In order to forewarn the drivers, the solar powered, soundless traffic light alarm should be installed at km 174 followed to warning message about steepness of 8.087% grade and dangerness of the road ahead on wide steel-sheet board can reduce the traffic crash significantly as a good practice at station km 107+000 between Dilela and Woliso town.
- ☞ In the long term interventions, from Station Km 28+800 (Sebeta, Dima) to Km 80+000 (Tulu Bolo) the full section of the carriageway should be uniformly overlaid by asphalt concrete.

Table 4.9: Frequency of Traffic Crash on Addis Ababa-Jimma Highway (2003 E.C - 2007 E.C)

	Frequency of Traffic Crash Occurred					
Woreda/City	**Fatal Injuries**	**Heavy Injuries**	**Slight Injuries**	**Property Damages**	**Total**	**Estimated Cost of PDO (ETB)**
Sebeta City	82	120	145	321	668	6,708,264.00
Sebeta Hawas	27	9	9	38	83	1,906,450.00
Ilu	26	7	10	20	63	1,953,850.00
Becho	28	22	7	10	67	2,918,780.00
Woliso	39	19	10	20	88	2,207,300.00
Woliso City	17	9	9	13	48	872,100.00
Goro	26	7	4	14	51	1,788,500.00
Kebena	7	13	9	14	43	1,512,250.00
Wolkite City	11	8	9	7	35	506,100.00
Abeshge	22	11	5	16	54	2,917,554.00
Yem Special	1	9	13	25	48	2,313,470.00
Sokoru	47	20	22	129	218	12,087,812.00
Omo Nada	20	15	10	40	85	2,308,878.00
Kersa	36	15	8	45	104	1,588,464.38
Grand Total	**389**	**284**	**270**	**712**	**1655**	**41,589,772.38**

Source: Collected from Woredas, Cities and Zonal Police Offices along the Route

Table 4.10: Severity of Traffic Crash on Addis Ababa-Jimma Highway (2003 E.C - 2007 E.C)

		No. of People Injured by Traffic Crash			
Zone	**Woreda/City**	**Fatal Injuries**	**Heavy Injuries**	**Slight Injuries**	**Total Injuries**
Special Zone	Sebeta City	84	160	199	443
Special Zone	Sebeta Hawas	27	9	9	45
S/W/Shoa	Ilu	32	18	19	69
S/W/Shoa	Becho	39	44	43	126
S/W/Shoa	Woliso	52	55	50	157
S/W/Shoa	Woliso City	34	18	24	76
S/W/Shoa	Goro	40	35	59	134
Gurage	Kebena	7	19	21	47
Gurage	Wolkite City	10	8	9	27
Gurage	Abeshge	32	20	24	76
Yem Special	Yem Special	1	25	33	59
Jimma	Sokoru	68	100	84	252
Jimma	Omo Nada	23	30	39	92
Jimma	Kersa	63	35	26	124
Grand Total		**389**	**284**	**270**	**712**

Source: Collected from Woreda’s Cities and Zonal Police Offices along the Route

4.1.2 Gibe Bridge (Km 185+700) to Deneba Town (Km 266+000)

Cross-Section

A. Gibe Bridge to Deneba (Towns Section)

Based on Addis Ababa-Jimma Road Rehabilitation Project Tender Documents Volume III-Section 2A (Gibe River-Jimma), the town sections from Gibe Bridge to Jimma town provided with 2.5m parking lanes were at the chainages listed in the Table 4.11.

Table 4.11: Length of Town Sections Provided with 2.5m Parking Lanes on Gibe-Jimma Road

Chainage	Location	Length (m)
185+760 to 186+100	Gibe	340
198+700 to 199+100	Abelti	400
211+500 to 212+500	Kumbi	1,000
225+900 to 226+800	Natri	900
238+000 to 239.200	Saja	1,200
250+000 to 251+650	Sokoru	1,650
264+400 to 267+000	Deneba	2,600
302+954 to 305+550	Asendabo	2,596
311+200 to 312+600	Harer	1,400
334+400 to 335+950	Serbo	1,550

However, there is no parking lanes of 2.5m and carriageway width of 6.5m on Ethiopian paved roads of DS1 to DS4, which is departure from ERA Geometric Design Standards. In addition to this, in many instances the full town sections provided with parking lanes and shoulders were reduced in length for the reason they would cover large areas with very little or no commercial activities instead wider shoulder/sidewalks were introduced in many of the longer town sections because this was considered to be sufficient for the pedestrian and animal traffic at that time. Whereas currently, these areas are mostly fall into the central part of these towns and creates abrupt changes of cross-sections which in turn the causes of safety risks in the towns in correspondence with the presence of long steep gradient in the town sections of Saja upto 6.754% grade, Sokoru 6.692% grade and Deneba 6.776% grade.

Even though, the research paper aimed to investigate effects of route and geometric design deficiencies on the road users, in addition to the above stated problems associated with geometric design attributes, since the road alignment passes through the hill foot, in the town sections of Saja, Sokoru and Deneba, the footway/sidewalk constructed on the fill side is degraded due to run-off from asphalt pavement across the steep side slope and climbing effect of humans and animals to the roadway for the reason of absence of ramp, which in turn reducing the capacity of the roadway, because pedestrians and animals are tends to walking on the traffic lane rather than using the footway/walkway.

Based on the traffic crash data of 2003 to 2007 Ethiopian fiscal year, compiled from the criminal record (CR) of Yem Special and Sokoru Woredas Police Offices, the traffic accident in these towns comprised of, Saja 27.1% (in Yem Special Woreda), Sokoru 6.25% and Deneba 11.64% (both in Sokoru Woreda). All these stated above problems in addition to the drivers (mostly younger drivers) inability to judge speed accurately in the towns and poor road usage behavior of the pedestrians, it has significant contributions to the traffic crash especially for vehicle-pedestrian collisions. Besides this, the traffic volume in terms of AADT on Wolkite-Jimma road segment had reached 1,453 in 2014 G.C traffic year (Table 4.4). Hence, in the town sections of Saja, Sokoru and Deneba

- ☞ In the long term interventions, the carriageway and parking lane should be widened as DS3, for the full length of town sections which is,
  Carriageway width = 7m,
  Parking lane width = 3.5m (on both sides)
  Footway/Sidewalks = 2.5m (on both sides)
- ☞ In the short term interventions, the shoulder/sidewalk of the roadway which is degraded should be reconstructed/replaced and supported by constructing retaining wall in order to encourage the pedestrians moving on the walkway.

Or it could be upgraded to DS2 based on further projections of traffic count for the design period to be intended.

Table 4.12: Traffic Crash Rate and Estimated Cost of PDO on Road Segments of Addis Ababa to Jimma Road (2003 E.C -2007 E.C.)

Name of the Road Segment	Chainage (Km)	AADT 2010-2014	Crash Freq.	Crash Rate	Estimated Cost of PDO ETB	Estimated Cost of PDO ETB/Km Road
Welete-Woliso	101	19199	1017	1.44	16,566,744	164,027.17
Woliso-Gibe	69.7	9880	183	0.73	6,724,404	96,476.38
Gibe -Deneba	80.3	5787	266	1.57	14,401,282	179,343.49
Deneba-Jimma	86.24	5785	189	1	3,897,342	45,102.91

Table 4.13: Traffic Crash Rate and Estimated Cost of PDO on Road Segments of Dima (Sebeta End) to Jimma Road 2003 E.C -2007 E.C

Name of the Road Segment	Chainage (Km)	AADT 2010-2014	Crash Freq.	Crash Rate	Estimated Cost of PDO ETB	Estimated Cost of PDO ETB/Km Road
Dima-Woliso	87.2	19199	349	0.57	9,858,480	113,055.96
Woliso-Gibe	69.7	9880	183	0.73	6,724,404	96,476.38
Gibe -Deneba	80.3	5787	266	1.57	14,401,282	179,343.49
Deneba-Jimma	86.24	5785	189	1	3,897,342	45,102.91

B. Gibe Bridge to Deneba (Rural Section)

According to Addis Ababa to Jimma Road Rehabilitation Project Final Project Report February 2010 document, the list of Typical Cross-section of the road segment recommended for the stations between Km 185+700 to km 268+954 (83.25 km) were as shown in Table 4.5. During feasibility study of road rehabilitation, one reason pointed by the consultant for the recommendation of the carriageway width of 3.0m and 3.25m as well as the shoulder width of 1.0m found in these stretches of the road was consideration of the width of existing culverts and bridge structures found in different stretches.

However, there is no carriageway width of 6m as well as 6.5m for Ethiopian paved roads of DS1 upto DS4 in current ERA Geometric Design Standard which are departure from standard. In addition to this, by the time, the traffic volume projected in terms of AADT 800 upto 2020 G.C for the design period of 25 years had outdated (regarding to traffic volume accommodating capacity) nine years before its end of design life in 2011 G.C. In contrast to this, the traffic count conducted on Wolkite – Jimma road section in traffic year 2014 G.C in terms of AADT has increased to 1,453 (Table 4.4).

During the field trips, the writer of this paper as discussed with Traffic Polices and officials working along the route for a long period of time, in addition to vehicles of Ethiopia, the road segment has currently giving service for South Sudan (which is a land locked country and far from Sea ports) for importing industrial goods and machineries from port of Djibouti and inputs of construction industry from Ethiopia by using Heavy-Trucks and Truck-Trailers. These conditions promising the presence of heavy vehicles on this road section will be tends to increasing more in the future and become hazardous on sharp horizontal (especially on switch-back) curves where larger vehicles need extra width to tract the curve.

On the other hand, as shown in the Table 4.18, the collision diagram of traffic crash occurred between 2004-2007 E.F.Y in Sokoru Woreda indicates that 11.1% of traffic crashes were involved by Vehicle-pedestrian collisions, 22.22% were Head-on collisions and 49.21% were Over-turning/Run-off-the-road (totally accounts 82.53) of Large-Buses, Heavy-Trucks and Truck-Trailers, mostly resulting from narrow cross-section of the roadway and bridges constructed on deficient horizontal and vertical alignment with numerous natural and man-made distant sight obstructions.

Though, all the above stated problems indicates that this road segment has deficiency of roadway cross-section in addition to horizontal and vertical alignment which in turn resulting severe road traffic crash rate of 1.57 which is ordered in 1st rank by exceeding the crash rate of road segments Addis-Woliso (including traffic crash in Sebeta town) 1.44, Woliso-Gibe Bridge 0.73 and Deneba-Jimma 1 with estimated property damages cost of 179,343.49 ETB/Km of road as shown in the Table 4.12. Whereas, when the traffic accident frequency in 13.8km of road section in Sebeta town deducted from this comparative analysis, the crash rate difference between the comparable segments is too vast, which are Gibe Bridge-Deneba (1.57), Deneba-Jimma (1), Sebeta (Dima)-Woliso (0.57) and Woliso-Gibe Bridge is (0.73) as shown in the Table 4.13. As the matter of fact, the cross-section of the road stretch should be widened (based on the 2014 G.C. traffic volume AADT 1,453) as DS3.

Hence, the cross-section of the roadway in the rural section should be:

- ☞ Carriageway Width = 3.5 m,
- ☞ Shoulder Width= 1.5m, (as the availability of RROW**)**

Adoption of shoulder width 1.5m is preferable, since the natural topography, Vegetable Trees and Shrubs always under fast growing along the road stretches mostly does not permit non-motor vehicles, pedestrians and animals are walking behind the roadway. Or it could be upgraded to DS2 based on further projection of traffic count.

Table 4.14: Density of Curves on Road Segments of Existing Addis Ababa to Jimma Road Based on Feasibility Study and As-built Design Drawing

Station (km)	Length (km)			% of Curves	Remarks
	Curve	Straight	Total		
10.67-185.7	27.48	147.55	175.03	15.7	
185.76-266	40.903	39.497	80.4	50.9	
266-352.24	24.614	45.726	70.34	35	Excluding realignment road

Vertical Alignment

A. Saja, Sokoru and Deneba (Town Sections)

On Addis Ababa to Jimma road, in Town sections of Saja from station Km 237+476 to 238+440 the road ascends steeply up to 6.75 % grade and from station Km 238+560 to 239+400 descends gently up to 5.66 % grade, in Sokoru from station Km 250+615 to Km 252+960 the road descending steeply up to 6.69 % grade and in Deneba from station Km 265+000 to 266+560 the road descending steeply up to 6.78 % grade. This characteristics of the road in town sections causing severe traffic accident resulting from Vehicle – Pedestrian collision and Vehicle-Vehicle collision due to long steep grade which in turn creating uncontrolled higher speeds of vehicles especially for loaded Truck-Trailers and old heavy vehicles. Hence, the town sections of:

- Saja: Km 237+476 to 238+560 to 239+400,
- Sokoru: Km 250+615 to 252+960 and
- Deneba: Km 265+000 to 266+560 should be provided at appropriate distance with Road humps or Speed breakers painted with white (preferably reflectorized) to make them visible at night and suitable road signs should also be placed to forewarn the drivers;
- Strict enforcement of speed limit control as per the design 35km/hr (for towns on Gibe Bridge to Jimma road section) preferably 30km/hr, by using electronic speed limit control devices such as handheld or vehicle mounted radar.

B. Gibe Bridge to Deneba (Rural Section)

According to Addis Ababa-Jimma Road Rehabilitation Tender Documents (Volume III – Section 2A, Gibe River Jimma), from Gibe River Bridge (km 185.7) at an elevation of 1,088m and after a mountainous, hazardous uphill course of 12.5 km comes out of Gibe gorge at Abelti (elevation 1.669) with an average grade of 4.4 %. The maximum grades are between 6 % and 7 %. From Abelti, the road route runs on the crest line between the Gibe and Gilgel Gibe basins for about 13.6 km on a hilly route until Kumbi (km 212), from where enters the Gilgel Gibe basin crossing tributaries of the main river on a predominantly mountainous alignment to reach, after 54 km from Abelti, the town of Deneba (km 266). In this part of its route the road passes through towns of Natri (km 226), Saja (km 238), and Sokoru (km 250).

On the other hand, based on the analysis of as-built design drawing of Addis Ababa to Jimma Road Rehabilitation Project, 41.5% of the vertical alignment fall into the category of 5%-10% while 58.7% fall into 0%-5%. The average grade is 4.13% followed by Deneba to Jimma (2.45%) and Addis to Gibe Bridge (1.5%) and the maximum grade is 9.65% (Table 4.8). These conditions indicates that the road segment has significant geometric design deficiencies associated with vertical alignment in correspondence with horizontal alignment. As the matter of this, the road section from Gibe River Bridge (km 185.7) to Deneba (km 266) concluded as major Black-spot road segment by the writer of this thesis.

Photo: Vehicle-vehicle Collision Occurred between Oil Truck-trailer, Mini-bus and Bajaj in Sokoru Town (Nov. 2015)

Horizontal Alignment

According to Addis Ababa-Jimma Road Rehabilitation Project Tender Documents Volume III-Section 2A (Gibe River-Jimma), the road section from Gibe River Bridge to Deneba town (km 185.76 to 266.00) alone, more than half (50.9) of the road route is formed by curves while 49.1% is formed by straight sections as re-arranged in Table 4.15.

On the one hand, based on the analysis of as-built design drawing of AutoCAD, from Addis Ababa to Jimma road, almost 94.74% of the narrowest curves (radius less than 40m) and all of the seven switch-back or hairpin curves (a radius of 20m or less, with a minimum of 13.75m) in correspondence with the steepest (max. 9.65% of grade) stretches of the road are found in the road section from Gibe Bridge to Deneba (Table 4.7 and 4.8). On the other hand, as shown in the Table 4.18, the collision diagram of traffic crash of 4 years, 2004 E.C-2007 E.C in Sokoru Woreda indicates that Over-turning/Run-of-the-road comprised 49.21%, Head-on collision 22.22% and Pedestrian collision 11.1% totally accounts 82.53% of crash type.

Table 4.15: Density of Curves on Existing Gibe Bridge to Deneba Road Segment during Feasibility Study

Stretch (km)	Length (km)			% Curves
	Curve	Straight	Total	
185.76-198.4	6.743	6.057	12.800	52.7
198.4-212.0	6.723	6.877	13.600	49.4
212.0-225.8	6.971	6.829	13.800	50.5
225.8-239.8	5.863	7.337	13.200	44.4
239.0-250.0	6.358	4.642	11.000	57.8
250.0-266.0	8.245	7.755	16.000	51.5
Total in km	**40.903**	**39.497**	**80.4**	**-**
Total in %	**50.9 %**	**49.1 %**	**100 %**	**-**

Photo: Switch-back Curve Having Radii of 13.75m in Correspondence with 5.83% grade Found in Sokoru Woreda (Shoshe) At Station Km 247+820.

In addition to this, Based on the traffic accident data of 5 years, 2003 – 2007 E.F.Y collected from the criminal record (CR) of Yem Special Woreda Police Office and summarized as in the Table 4.17, Over-Turning/Run-off-the-road (including falling) of vehicles comprised 62.5%, Vehicle-Vehicle Collision 20.83% and Vehicle - Pedestrian Collision 16.67%, totally accounts of 100% (not identified by collision diagram) of the crash type. Surprisingly, the percentage of crash types of Sokoru and Yem special (partially enclosed by Sokoru Woreda) nearly similar and they are clearly an additional indicator of deficiencies of roadway cross-section, horizontal and vertical alignment on this road segment.

Due to the fact of all these geometric design deficiencies, during feasibility study of road rehabilitation project, in this road segment, from km 185.7 to km 267, the design speed recommended were must limited to 40 km/hr due to high density of curves, mainly with radii less than 120m in correspondence with longitudinal slopes mostly between 4%-6%.

Particularly, there are two stretches of road, namely in the last 5 km of the Gibe gorge near Abelti (km 193 to 198) and between Saja and Deneba (km 238.5 to 255) where the road crosses the valleys of Kosho and Simini rivers the recommended speed limits were reduced to 20-35 km/hr, due to the concentration of narrow bends (radii less than 40m) and steep longitudinal slopes (5-7%). In this stretch of road, several bridges like Kosho River Bridge at km 246+120 (in reverse curves of radii 20m and 22m) and Simini River Bridge at km 246+856 (in broken-back curves of radii 30.8m, 74m and 27.5m) are located in sharp horizontal curves.

Based on the above analysis carried out by the writer of this thesis, the road section from Gibe River Bridge to Deneba (Station km 185+700 to km 266+000) has significant deficiency of horizontal alignment. Hence to alleviate these problems short term (low cost) and long term (high cost) engineering interventions (measures) has recommended. Hence,

- In the long term interventions Re-alignment of the road should be required for the road sections Gibe Bridge to Abelti town and Saja town to Sokoru town.
- For particular black-spot areas short term and long term engineering interventions has recommended and summarized in the Table from 4.24 to 4.28 listed below.

Photo: Narrow (6m) Bekere River Bridge Found in Sharp Horizontal Curve (Curve Radii 26m) in Sokoru Woreda at Station Km 247+216

4.1.3 Deneba Town (Km 266+000) to Jimma Town (Km 352+241)

Cross-Section

A. Deneba to Jimma (Town sections)

Based on Addis Ababa-Jimma Road Rehabilitation Project Tender Documents Volume III-Section 2A (Gibe River-Jimma), the town sections from Deneba to Jimma provided with 2.5m parking lanes were at the chainages listed in the Table 4.5. Whereas, there is no parking lanes of 2.5m in Ethiopian paved roads of DS1 to DS4, which is departure from ERA Geometric Design Standards. On the one hand, the full town sections with parking lanes and shoulders were reduced in length for the reason they would cover large areas with very little or no commercial activities, instead wider shoulders/sidewalks were introduced in many of the longer town sections because this was considered to be sufficient for the pedestrian and animal traffic at that time.

However, those parts of the town sections by the time considered as with very little or no commercial activities are currently fall into the central part of the these towns. This abrupt changes of cross-sections which in turn the cause of traffic crash in the towns, since the speed limit traffic signs of 30 km/hr installed during road rehabilitation were currently found in the central part of these towns and it causes a negative impact on the drivers entering the towns without change of speed reduction as observed in Asendabo town. Hence,

- The 30 km/hr speed limit signs should be re-installed at the entrance and appropriate location of the towns like Asendabo and Serbo.
- In the long-term interventions the roadway cross-section in towns of Serbo and Asendabo should be widened as DS3 for the full length of town section:

  Parking lane = 3.5m (on both sides), Footway = 2.5m,

Or it could be upgraded to DS2 based on further projections of traffic count for the design period to be intended.

B. Deneba to Jimma (Rural Section)

According to Addis Ababa to Jimma Road Rehabilitation Project Final Project Report February 2010 document, the towns passed through by the road in this last portion are Asendabo (302+170), Gilgel Gibe (307.22), Arer (310.22), and Serbo (333.22) and terminate at Jimma (352+241). The list of typical cross – section of the road segment recommended during feasibility study for the station between Km 268+954 to Km 352+241 were as shown below,

Km 268+954 to km 302+170 (33.22 km)	Carriageway = 3.50m,	Shoulder = 1.50m
Km 302+170 to km 352+241 (50.1 km)	Carriageway = 3.50m,	Shoulder = 1.00m

During Feasibility study of Addis-Jimma Road Rehabilitation Project, the traffic volume forecasts in terms of AADT were 800 for Wolkite-Gilgel Gibe and 900 for Gilgel Gibe-Jimma projected up to 2020 G.C for the design life of 25 years were outdated (regarding to traffic volume accommodation capacity) nine years before its end of service life in 2011 G.C as Gibe Bridge-Deneba road segment. Since the traffic count conducted on Wolkite – Jimma road section in traffic year 2014 G.C in terms of AADT had increased to 1,453 (Table 4.4) and hence the terrain in which the road stretch traverses is mostly a rolling to hilly alignment, the shoulder of the road stretch should be widened uniformly (by keeping the Carriageway width as 7m) as DS3:

Hence, the cross-section of the road from station Km 268+954 to 352+241 should be:

- Carriageway width = 7m,
- Shoulder width = 1.5-3.0m, preferably 3m (as the availability of RROW)

Photo: Traffic Crash Occurred between Sino-Truck High-bed and N_3 Truck on Narrow Mendio River Bridge (Oct. 19/2015 G.C.)

Horizontal Alignment

According to Addis Ababa to Jimma Road Rehabilitation Project Final Project Report February 2010 document, from the total length of the road segment 70.34 km (excluding the alignment road), the length of the curves accounts 24.614 km (35%) while the tangent (straight) sections accounts 45,726 km (65%) as shown in the Table 4.16. This road stretch is relatively a winding alignment, in which numerous bends have radii greater than 240m, unlike Gibe Bridge to Deneba town.

However, when comparing the deficiencies on horizontal alignment of this road section with Gibe Bridge to Deneba road segment, it is quite contrast except between station 347+216 to 348+716, which comprises of sharp reverse curves (including narrow curve having radii of 31m) in correspondence of longitudinal slope of 5.5-6.5 % grade.

Table 4.16: Density of Curves on Existing Deneba to Jimma Road Segment during Feasibility Study

Stretch (km)	Length (km)			% Curves
	Curve	Straight	Total	
266.0-290.3	6.059	18.241	24.3	24.9
290.3-310.0	7.482	12.218	19.7	38.0
310.0-318.0	4.090	3.910	8.0	51.1
318.0-336.3	6.983	11.357	18.34	38.1
Total in km	**24.614**	**45.726**	**70.34**	**-**
Total in %	**35%**	**65%**	**-**	**-**

Hence, to alleviate the traffic crash associated with horizontal alignment deficiencies of this black-spot area between station km 347+216 to km 348+716:

- ☞ In the long-term intervention re-alignment of the road should be required.
- ☞ Short-term engineering interventions are listed in the Table 4.21-4.28.

Photo: Warning Message of the Forthcoming Road at Station 347+300 (Beda Buna) on Wide Steel Board

Vertical Alignment

In this road section, from Deneba the road runs between elevations 1,700m and 1,800m on a rolling to hilly alignment up to the town of Jimma (352+241), initially descending to cross the Gilgel Gibe River (minimum elevation 1,682 m) and then preceding on the left flank of the valley to reach elevation 1,800m at Beda Buna (km 347+216), from where it reaches Jimma with a steep downgrade of (6.6%) and several successive horizontal curves.

In general, in this road section, there is no significant problem associated with vertical alignment since 87.9% of vertical gradient fall into 0%-5% and there is no grade departure from ERA geometric design standard except the road stretch between stations km 347+216 to 348+716 having maximum downgrade of 7.865% in correspondence with sharp reverse horizontal curves of having minimum radii 31m which is concluded as black spot area by the writer of this thesis.

Hence, to alleviate the traffic crash associated with vertical alignment deficiency of this black-spot area between station km 347+216 to km 348+716:

- ☞ **In the long-term intervention re-alignment of the road should be required.**

Photo: Steep Downgrade of 7.865% in Correspondence with Successive Sharp to Reverse Curves (Consisted of Radii 31m) at Beda-Buna Approach Jimma Town.

4.2 Effects of Highway Route Location and Geometric Design Deficiencies on the Road Users on Addis Ababa to Jimma Road

It is much better to have a bad road in a good location than it is to have a good road in a bad location. A bad road can be fixed. A bad location cannot. Most of the investment in the bad road can be recovered, but little, if any, can be recovered from a bad location! (Low-volume Roads Engineering: Best Management Practices Field Guide, Gordon Keller & James Sherar, July 2003). Road design, construction and maintenance require an approach depending on the terrain. Hence, the shortest road alignment is not necessarily the easiest, quickest or most economical option for construction and maintenance (ERA Geometric Design Manual, 2002).

Addis Ababa to Jimma Road was constructed by the Italians more than 70 years ago. The road section through the Gibe Gorge comprised what, at that time, was considered to represent the optimum route and most certainly consisted of very significant volumes of rock cut and fill to construct a platform that was adequate for the intended uniform carriageway width of 6m (Addis Ababa to Jima Road Rehabilitation Project Final Project Report, February 2010 document).

Even though today, after the Ethiopian Roads Authority (ERA) conducted rehabilitation measures (with minor changes of route and geometric design features) in 1990's E.C, there is still noticeable deficiencies of geometric design features especially on the road section between Gibe River Bridge to Deneba Town which is concluded as a major black spot road segment by this comparative study. The major adverse effects observed both on the road users and for the government in relation with route and geometric design deficiencies on the road section Gibe River Bridge to Deneba town are listed below.

1, Road Traffic Crash;

2, Highway Drainage Crossing Structures Relocation Cost.

4.2.1 Road Traffic Crash

Based on the five years, 2003 to 2007 E.F.Y road traffic crash analysis carried out on 11 Woredas and 3 City Administrations traverses by Addis Ababa-Jimma Road, Sokoru and Yem Special (partially enclosed by Sokoru Woreda) Woredas which are found on the road stretch between Gibe Bridge to Deneba Town station km 185+700 to 266+000 (80.3 km) is concluded as a critical traffic crash (Black-spot) road segment on Addis Ababa-

Jimma road in relation with geometric design features deficiencies by the writer of this thesis. The two reasons for this conclusion are stated below.

A. Road Traffic Crash Rate

Based on the calculation carried out for the comparative analysis of traffic crash rate, by including the traffic accident data of Sebeta city in Addis (Welete Suk)-Woliso road segment, the traffic crash rate of Gibe Bridge to Deneba road section has scored the greatest value of 1.57 followed by Addis to Woliso 1.44, Woliso-Gibe Bridge 0.73, and Deneba-Jimma road section has scored 1 as shown in the Table 4.12.

However, conducting comparative analysis of traffic crashes between the road sections by including towns like Sebeta is too difficult and it may leads to an error. Since Sebeta city (which is now completely connected with Addis Ababa) is heavily trafficked, developed area and the junction of two routes (Addis-Jimma and Alemgena-Arbaminch road) where 61.63% of accidents were occurred by vehicle-pedestrian collisions mostly caused due to high speed of vehicles on undivided carriageway and relatively on narrower cross-sections of the road in addition to the drivers inability to judge speed accurately (mostly younger drivers) and pedestrians poor behavior of road usage in town sections.

Hence, when the traffic accident frequency in 13.8km of road section in Sebeta town deducted from this comparative analysis, the crash rate difference between the comparable segments is too vast, which are Gibe Bridge-Deneba 1.57, Deneba-Jimma 1, Sebeta (Dima)-Woliso 0.57, and Woliso-Gibe Bridge 0.73 as shown in the Table 4.13. As the matter of fact, this road section has significant deficiency in relation to route and geometric design features.

B. Frequency of Road Traffic Accident by Crash-Type

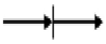
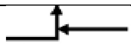
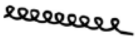
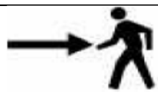
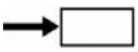
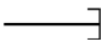
One reason for the conclusion of Gibe Bridge-Deneba road segment as black-spot road segment can be noticed simply from the comparative analysis of the traffic crash data collected from Yem Special Woreda Police Office Criminal Record (CR) as summarized in the Table 4.17. Based on road traffic crash of 5 years occurred between 2003 E.C - 2007 E.C fiscal year, Over-Turning/Run-off-the-road (including falling) of vehicles comprised **62.5%**, Vehicle-Vehicle Collision **20.83%** and Vehicle-Pedestrian collision **16.7%** (not identified by collision diagram) crash type totally accounts **100%**.

On the other hand, based on the data obtained from Jimma Zone Police Department and Sokoru Woreda Police Office, traffic crash collision diagram of Sokoru Woreda 4 years, 2004 E.C-2007 E.C fiscal year as summarized in the Table 4.18, Over-turning/falling comprised of **49.21%,** Head-on collision **22.22%** and Pedestrian collision **11.1%** totally accounts **82.53%** of crash type. The crash type of Sokoru and Yem Special (partially encircled by Sokoru) Woredas are nearly almost similar since the road section has similar geometric characteristics. Hence, these crash types are mostly a consequences of narrow cross-section of the road and bridges and deficiencies of horizontal and vertical alignment on the road segment.

Table 4.17: Frequency of Accident by Crash-Type in Yem Special Woreda from 2004 E.C to 2007 E.C Fiscal Year

	2003	2004	2005	2006	2007	Total	% age
Over Turning/Falling	2	8	6	8	6	30	62.5
Vehicle - Vehicle Collision	3	3	-	2	2	10	20.8
Vehicle - Pedestrian Collision	2	-	-	4	2	8	16.7
Collision With Cattle/Object	-	-	-	-	-	-	-
Unmentioned	-	-	-	-	-	-	-
Total	**7**	**11**	**6**	**14**	**10**	**48**	**100**

Table 4.18: Frequency of Accident by Crash-Type in Sokoru Woreda from 2004 to 2007 E.C Fiscal Year

Type of Crash Collision	Collision Diagram	Frequency of Accident by Crash-Type					
		Fatal Injury	Heavy Injury	Slight Injury	Property Damage	Total	%
Head On Collision		6	1	3	32	42	22.22
Rear End Collision		-	-	-	2	2	1.06
Turning Collision		1	-	1	6	8	4.23
Sideswipe Collision		1	1	1	6	9	4.76
Overturning/ Run-off-the-Road/ Run-off-the-lane		11	5	15	62	93	49.21
Pedestrian Collision		15	6	-	-	21	11.1
Animal Collision		-	-	-	1	1	0.53
Falling From Vehicle		-	-	2	3	5	2.65
Collision with Stopping vehicle		-	-	-	1	1	0.53
Collision with Fixed Object		-	-	-	2	2	1.06
Others		1	2	-	2	5	2.65
Total		**35**	**15**	**22**	**117**	**189**	**100**
% age		**18.52**	**7.94**	**11.64**	**61.9**	**100**	

C. Estimated Cost of Property Damages Only (PDO)

Based on five years, 2003 to 2007 E.F.Y traffic crash data collected from 11 Woredas and 3 City Administrations Police Offices, another reason for the conclusion of the road stretch Gibe Bridge to Deneba town as a major black spot road segment in relative to geometric design deficiencies is based on comparative study of estimated cost of property damages occurred by road traffic crash on the road segment length of 80.3km which accounts 23.5% (from the total road length of 337.241km, Welete Suk-Jimma) comprised about **Birr 14,401,282.00 (**179,343.49 ETB/Km**)** as summarized in Table 4.12, from the total property damages of **Birr 41,589,772.38** occurred in total road length of 337.241km of Welete Suk-Jimma road in contrast to frequency of traffic crash involved property damages only (PDO) on the road segment Welete-Woliso 4.18, Woliso-Gibe Bridge 0.73, Gibe Bridge-Deneba and Deneba Jimma 0.98. This huge amount of property damages is mostly resulting from Over-Turning/Run-off-the-road (including Falling) and Head-On collision of Heavy-Trucks, Truck-Trailers and large Buses, causing due to deficiencies of geometric design alignment and narrower cross section of the roadway and bridges located in sharp simple circular curves, reverse curves and broken-back curves in addition to poor driving behavior of the drivers.

Photo: Vehicles Collisions Occurred Between Oil Truck-Trailer, Mini-bus & Bajaj in Sokoru Town (Nov, 2015).

4.2.2 Highway Drainage Crossing Structures Re-location Cost

Based on four years (2012 G.C-2015 G.C.) highway structures relocation and maintenance cost data obtained from ERA, Alemgena Road Network Management Directorate and ERA, Jimma Road Network Management Directorate, on the road section Addis Ababa to Gibe Bridge (175.03 km) there was no drainage crossing structures cost for relocation of Bridges and Culverts since there is no significant geometric design deficiencies in the location of bridges.

Relatively, on the road section Gibe Bridge to Jimma (166.541km) the cost of drainage crossing structures for relocation of two Bridges and two Culverts (all of them are located between the road stretches Gibe Bridge to Deneba town) and re-alignment of its approaches for the same four years was ETB 41,673,094.63. All of the four Bridges and Culverts are found on the road segment Gibe Bridge to Deneba and to be relocated for the reason they considered as a particular black-spot area along the road segment contributing higher percentage of traffic crashes since they are found, Kosho Bridge located in sharp reverse curves having radii of 20m and 22m, Simini Bridge in broken-back curves having radii of 30.8m, 74m and 27.5m, Bekere Bridge in sharp curve of radii 26m and Kore Bridge located in part of reverse curves having radii of 69.4m.

In general, all these costs on the road segment Gibe Bridge to Deneba, mostly associated to the presence of high density of sharp horizontal curves including seven Switch-back curves (curve radii less than 20m), successive reverse curves (S-Curves), Broken-back curves (C-Curves) in correspondence with steep gradient, narrower road cross-sections and existence of narrower bridges in sharp horizontal curves. As the matter of fact, the road segment from Gibe Bridge to Jimma Town especially the road stretch from Gibe Bridge to Deneba town, has currently forced the government to investing a huge amount of cost for relocation of drainage crossing structures cost due to initial deficiencies of route and geometric design attributes.

Table 4.19: Addis Ababa to Jimma Road Bridges/Culverts Relocation Cost 2012 -2015 G.C

Road Segment Name	**Chainage (km)**	**Bridges/Culverts Relocation Cost (ETB)**	Remarks
Addis-Gibe Bridge	175.03	-	No Bridge relocation
Gibe Bridge-Deneba	80.3	41,673,094.63	Bridge relocation cost includes realignment of approaches road
Deneba-Jimma	86.241	-	No Bridge relocation
Total	341.571		

Photo: Kosho Bridge both Existing and Re-located Bridge

Photo: Simini Bridge both Existing and Re-located Bridge

Table 4.20: Summary of Research Findings on the Main Causes of Traffic Crashes on Addis Ababa-Jimma Highway

a) Addis Ababa to Gibe River Bridge Road Segment
➢ The existence of parking lanes in reduced length and absence of median island between the traffic lanes in the town sections found along the road segment; ➢ The narrower cross-section of the road in rural parts of Addis-Gibe road section; ➢ The presence of long tangent sections (above 4km length) of horizontal curves; ➢ Defects of unevenness in longitudinal and transverse profile of asphalt concrete pavement over large parts of the road segment from Sebeta to Tulu bolo town; ➢ Absence of transitional speed zones on approach road to the towns; ➢ The lesser the strict speed limit control as per the road design; ➢ The presence of 42.61% of vertical alignment into the category of 5%-9% grade and maximum grade of 8.087% between stations km 174+000 to km 185+700.
b) Gibe Bridge to Deneba Road Section
➢ The existence of 6m and 6.5m wide narrower road section in rural parts; ➢ The presence of high density of curves, more than half (50.9%) of the route is formed by horizontal curves; ➢ The existence of 94.74% of the narrowest curves (radius less than 40m) and all of the seven Switch-back/hairpin curves (radii of 20m or less, with a minimum of 13.75m) are found in correspondence with the steepest stretches of the road; ➢ The existence of several narrower bridges found in sharp horizontal curves in correspondence with the steepest downgrades. ➢ The existence of 41.3% of the vertical alignment into the category of 5%-10% grade, average grade of 4.13% and maximum grade of 9.65% on the road section. ➢ The presence of long steep downgrade between the range of 5.66%-6.78% found in towns of Saja, Sokoru and Deneba; ➢ The presence of narrow parking lane width of 2.5m (departure from ERA GDS) with reduced length in the town sections of Natri, Saja Sokoru and Deneba; ➢ The presence of degraded footway/sidewalk in the town sections of Saja, Sokoru and Deneba; ➢ The absence or limited presence of curvedness, narrow bridge, grade steepness and speed limit indicator signs and road side delineators as the required level; ➢ Limitations on trimming natural and manmade distant sight obstructions found

adjacent to the inner lane of the curve as the required time and level; ➢ Limitations on enhancement of advanced method of speed limit control and law enforcement as per the design of the road.
c) Deneba to Jimma road Segment
➢ The presence of narrow parking lane width of 2.5m with reduced length in the town sections of Asendabo, Harer and Serbo; ➢ The presence of successive reverse curves (curve radii of 31m) and broken-back curves in correspondence with steep gradient of 5.5-6.5% at Beda Buna; ➢ Absence of transitional speed zones on approaches road to the towns; ➢ The presence of most of speed limit signs fall in the mid-section of the town which were installed at the edge of the town during the time of rehabilitation.

In addition to all the above conducted results and discussions, based on the Traffic Polices crash report data of frequencies, causes and severity of traffic crashes and after site investigations through trips with the help of Traffic Polices working along the route for a long period of time in combination of the analysis of Addis Ababa-Jimma Road Rehabilitation Project As-built Design Drawing, Tender and Final Project Report documents, black-spot particular sites and engineering deficiencies observed on those sites were identified. Finally short-term (low cost) and long-term engineering interventions for the black-spot road segment and particular black-spot areas were recommended as listed in the Tables 4.21 upto 4.28.

Table 4.21: Severity of Traffic Crash on Black-Spot Areas on Addis-Gibe Road

Special Name	Station in Km from A.A	Frequencies of Traffic Crash Type by Number	Causes of Traffic Crash Type by Number	Accident Severity (2003 -2007 E.C.)				Crash Frequencies
				Fatal Injuries	Major Injuries	Slight Injuries	Property Damages Only in ETB	
1	2	3	4	5	6	7	8	9
Sebeta City	10+67 to 28+00	Over turning (18), Vehicle-Vehicle collision (3), Unmentioned (4)	High Speed (3), Carelessness (7), Technical problem (1), Design deficiency (2), Driving on opposite lane (1), Unmentioned (11)	84	160	199	6,779,080.00	668
Becho Plain	28+80 to 80+00	Over-turning, Vehicle-Vehicle collision, Vehicle-Pedestrian collision	High Speed, Carelessness and Driving on opposite lane (1)	98	71	71	178,000.00	213
Rebu Bridge	146	Over-turning and Head-On collision	Road Geometric Design Deficiency	3	1	8	679;300.00	14
Guest House/ Palace	150.9	Run-of-the-road, Over-turning		-	7	9	482,000.00	12
Gibe Valley	174+00 to 185+70			1	3	5	1,281,098.00	12

Table 4.22 Observed Design Deficiencies of Black-Spot Areas on Addis-Gibe Road

Special Name	Station in Km from A.A	Observed Engineering Deficiencies of the Road During Site Visit and Data Analysis
1	**2**	**3**
Sebeta City	10+670 to 28+000	* The presence of narrow cross-section of the road since from the total length of 18.13km of the town section, only 4.1km (22.61%) provided with parking lane in turn creating safety risks in the town. * There is no median island between the traffic lanes which can be used as a refugee area for minimizing safety risks on pedestrians crossing the road.
Becho Plain	28+800 to 80+000	* Defects of unevenness in longitudinal and transverse profile due uneven maintenance on AC pavement over large parts of the road which in turn lead to jumping of vehicles and loss of control (especially two wheelers) causing run-off-the-road/run-off-the-lane resulting rollover, collisions with vehicles, road side objects and pedestrians walking on the shoulder.
Rebu Bridge	146	* The existing 6m Rebu Bridge is too narrow and hence unable to pass vehicles (especially large size) safely. * Masonry barrier on the bridge has damaged by Over-Turning impacts of Vehicles. * Rebu bridge is constructed in "broken-back" horizontal curves having a radius of 165m and 100m in correspondence with grade 4.106 % grade in descending and 3.867 % grade in ascending direction (when approach from Addis).
Guest House/ Palace	150.9	* Even if the area has limited distant sight obstructions there is long steep gradient consisting of 6.91 % grade, but no traffic signs and warning messages observed along the road.
Gibe Valley	174+000 to 185+700	* The road passes through escarpment of Gibe valley where the maximum of 8.087% grade is found and 42.61% of the vertical alignment fall into the category of 5%-9% grade

Table 4.23: Engineering Interventions on Black-spot Areas on Addis-Gibe Road

Station in Km from A.A	Proposed Possible Interventions	
	Short-Term Engineering Interventions	**Long-Term Engineering interventions**
1	**2**	**3**
10+670 to 28+000	* Prohibiting stopping of vehicles for long time on the road section which were constructed without parking lanes.	* The town sections from Ayer Tena station km 10+670 to km 28+800 Sebeta (Dima) could be uniformly provided with Parking lane of 3.5m and Walkway of 2.5m wide on both sides of the way. * The median island could be provided between the traffic lanes for the full length of the town section along the road.
28+800 to 80+000	* As much as possible uneven maintenance work should be avoided.	* From station km 28+000 to km 80+000 total overlay of asphalt concrete preferably recommended.
146	* Providing warning message indicates narrow bridge in the curve ahead on wide board at appropriate location on both approaches of the bridge. * The damaged masonry barrier should be maintained and extended by steel sheet guard rail at least by 20m at both edges.	* To reduce/avoid the sharpness of the curve the bridge could be relocated on the upstream side of the existing bridge and replaced by the wide one.
150.9	* Traffic sign indicator of speed limit and steepness of the grade followed to warning message about the forthcoming road could be installed for the descent incoming drivers at station km 151+240 (exit to Addis from Wolkite town).	-
174+000 to 185+700	* In order to forewarn the drivers, the solar powered, soundless traffic light alarm could be installed at km 174 followed to warning message about steepness of 8.087% grade and dangerness of the road ahead on wide steel-sheet board.	-

Table 4.24: Severity of Traffic Crash On Black-Spot Areas On Gibe-Jimma Road

Special Name	Station in Km from A.A	Frequencies of Traffic Crash Type by Number	Causes of Traffic Crash Type by Number	Accident Severity (2003 -2007 E.C)				Crash Frequencies
				Fatal Injuries	Major Injuries	Slight Injuries	Property Damages Only in ETB	
1	2	3	4	5	6	7	8	9
Shen Debitu	194.5	Over turning (18), Vehicle-Vehicle collision (3), Unmentioned (4)	High-Speed (3), Carelessness (7), Technical problem (1), Design deficiency (2), Driving on opposite lane (1), Unmentioned (11)	4	1	1	1,365,820.00	25
Bede	201	Over-turning (8), Vehicle-Vehicle collision (3), Vehicle-Pedestrian collision (1)	Carelessness (3), High Speed (2), Driving on opposite lane (1) and Unmentioned (6)	2	-	2	178,000.00	12
Muz Tera	209.6	Vehicle-Vehicle Collision (2), Over-turning (1), Vehicle-Pedestrian Collision (1)	Over-speed (2), Run-off-Road (1), Unmentioned (1), Road Design Deficiency	1	-	1	88,000.00	4
Kumbi Town	212	Vehicles-Vehicle Collision (3), Vehicle-Pedestrian Collision (1), Overturning (4), Unmentioned (4)	Carelessness (4), Over-speed (3), Driving on opposite lane (1), Unmentioned (4)	3	-	1	309,000.00	12

Table 4.24: Severity of Traffic Crash On Black-Spot Areas On Gibe-Jimma Road

1	2	3	4	5	6	7	8	9
Wolene River Bridge	217.02	Over turning (2), Vehicle-Vehicle Collision (1), Vehicle-Pedestrian Collision (1)	High-speed (1), Driving in sleeping (1), Unmentioned (2), Road Design deficiency	2	-	-	392,000.00	4
Dobi	221.05	Over turning (1), Vehicles Collision (1), Unmentioned (2)	High-speed (1), Unmentioned (3), Road design deficiency	2	4	2	17,000.00	4
Doma	231.4	Over-Turning (3), Vehicle-Vehicle collision (1), Vehicle-Pedestrian collision (1), Unmentioned (1)	Unmentioned (6)	-	-	3	119,000.00	6
In front of Ashe Police Office	234.2	Over-Turning (11), Vehicle-Vehicle collision (6), Vehicle-Pedestrian collision (4),	Unmentioned (21)	1	8	15	1,046,000.00	
Saja Town	238	Over-Turning (7), Vehicle-Vehicle collision (2), Vehicle-Pedestrian collision (4),	Unmentioned (13)	-	14	17	600,000.00	13

Table 4.24: Severity of Traffic Crash On Black-Spot Areas On Gibe-Jimma Road

1	2	3	4	5	6	7	8	9
Kosho River Bridge	241.75	Over-turning (8), Vehicle-Vehicle Collision (3), High-speed (1)	Unmentioned (11)	1	1	2	574,500.00	11
Bekere River Bridge	246.22	-	-	-	-	-	-	-
Simini River Bridge	246.86	Over-turning (4), Unmentioned (1)	Carelessness (2), High-speed (1), Driving on opposite lane (1), Unmentioned (1), Road Alignment deficiency	-	6	1	88,000	5
Shoshe	247.82	-	-	-	-	-	-	-
Sokoru Town	250	Vehicle-Vehicle Collision (4), Vehicle-Pedestrian Collision (2), Strapping (1), Unmentioned (2),	Carelessness (3), Over-Speed (1), Disallowing priority for pedestrians (1), Unmentioned (4)	5	1	-	38,700	9
Awano	254.1	-	High Speed	-	-	-	-	-
Birile River Bridge	255.13							
Kore River Bridge	256.8	Vehicle-Vehicle Collision (4),	High Speed (2), Disallowing Priority (2) and Road design deficiency	-	-	-	121,300.00	4
Teyar River Bridge	257.52	-	High-speed	-	-	-	-	-

Table 4.24: Severity of Traffic Crash On Black-Spot Areas On Gibe-Jimma Road

1	2	3	4	5	6	7	8	9
Gilgel Gibe HEP Office	258	Vehicle-Pedestrian Collision	High-speed	-	2	1	-	1
Wuha Limat	262	Pedestrian Collision and Run-off-the-road	High-speed and Road design deficiency	-	1	1	-	1
Deneba River Bridge	264	Head-on Collision	High Speed	-	-	2	huge	2
Deneba Town	265	Vehicle-Vehicle Collision (6), Vehicle-Pedestrian Collision (5), Overturning (3), Collision with object (1), Unmentioned (2)	Carelessness (5), Over-speed (3), Driving on opposite lane (1), Unmentioned (8)	2	2	2	624,400	17
School Area	266	Over-turning, Vehicle-Pedestrian Collision	Overtaking, Disallowing priority for Pedestrians	-	2	1	huge	4
G/Gibe Bridge	290.3	Over-turning						
Beda Buna	348	Over-turning	High-speed and Road design deficiency	4	2	2	huge	5

Table 4.25: Observed Design Deficiencies on Black-Spot Areas on Gibe-Jimma Road

Special Name	Station in Km from A.A	Observed Engineering Deficiencies of the Road During Site Visit
1	**2**	**3**
Shen Debitu	194.5	* The concentration of narrow bends (radii less than 40m) in correspondence with steep slopes of 5%-7% grade. * As the location is found in too sharp curve having radii of 13.75m, there is no traffic warning signs are observed. * The Back-slope adjacent to the inner lane of the curve is covered with Bush and Trees which obstructs distant vision in turn leading to Head-on collision and Run-off-the-road. * The existing curve widening in the inner lane side has damaged. * As the terrain adjacent to the outer lane of the curve is partially cliff and partially fill section with steep side-slope, there is no barrier/guard rail to protect the vehicles from run-off-the-road as well as collisions of vehicles to adjacent cliff. * No speed-limit sign was provided.
Bede	201	* No road Signs were observed when approaching to the location. * The location has "broken-back" horizontal curves (having a short tangent between two successive curves in the same direction) and hence drivers do not generally anticipate successive curves in the same direction. * Adjacent to the inner lane of those curves are covered with Trees and Bushes which hindering distant vision. * Both sides of shoulders/sidewalks are covered with brushes hence pedestrians are unable to walk on the shoulder, rather they are forced to use the carriageway with vehicles which are causing Vehicle-Pedestrian collision, Over-turning and Head-on collision for the sake of saving human life.
Muz Tera	209.8	* Speed-limit sign is not provided. * Neither guard rail nor appropriate warning sign is provided as the station is located in sharp broken-back curves of radii 52.5 and 160m and terrain adjacent to the outer lane of the curve is depression (Low point). * Back slope adjacent to the inner lane of the curve is obstructing distant sight. * Bushes and Vegetable Trees found adjacent to the inner lane of the curve is obstructing Sight distance.
Kumbi Town	211.83	* The station is located in sharp horizontal curve of radii 50m. * Neither guide post nor guard rail is provided. * No speed-limit sign is observed.

Table 4.25: Observed Design Deficiencies on Black-Spot Areas on Gibe-Jimma Road

1	2	3
Wolene River Bridge	217.02	* When approaching from Addis to the site, the culvert is narrow and located in sharp curve having radii of 48.50m which is a part of broken-back curves following steep downgrade. * When approaching from Addis to the site, between stations 217+000 to 217+060 in the inner lane of the curve there is plenty of Eucalyptus tree and bushes which obstructing distant vision. * There is no sharp curve and narrow bridge indicator sign on both approaches
Dobi	221.05	* When approaching from Addis to the site, Getta river bridge is located in broken back curves having radii of 45m and 68.5m and its approaches road is consist of reverse curves in addition to long steep down grade. * Speed-limit sign is not provided in both approaches. * Neither guard rail nor appropriate warning sign is provided as the station is consists of broken-back sharp curves and terrain adjacent to the outer lane of the curve is depression (Low point). * Back slope adjacent to the inner lane of the curve is obstructing Sight distance.
Doma	231.4	* When approaching from Addis, the bridge is located in broken-back curves having radii of 71m on both ends with small tangent section in between in addition to steep downgrade of the road. * When approaching from Jimma to the bridge site, there is another broken-back curve with small tangent section in addition to the Bridge site. * Bridge is not visible from distant especially when approaching from Addis because of plenty Bushes and Trees covering the area. * When approaching from Jimma to the bridge site, there is no curve and narrow bridge ahead indicator signs on both approaches road.
In front of Ashe Police Office	234.2	* At Station 234+200 (In front of Ashe Police Office) when approach from Addis, on the cut section (LHS) of the roadway, there is no ditch/side-drain constructed to convey flood and mud-flow from the back slope side of mountainous area as well as the roadway which is causing mud and silt deposition on Asphalt concrete pavement during rainy season resulting significant reduction of skid resistance of vehicles in turn causing Over-turning, Run-off-the-road and Run-off-the-lane of vehicles.

Table 4.25: Observed Design Deficiencies on Black-Spot Areas on Gibe-Jimma Road

1	2	3
Saja Town	238	* When approaching from Addis, at the entrance of Saja town starting from station Km 237+476 to 238+440, there is a steep ascend upto 6.754 % and then from station Km 238+560 to 239+400 a steep descend up to 5.655 % in addition to the presence of reverse curves and broken-back curves in the town. * In the town sections of Saja starting from station Km 238+400 to 238+800 the shoulder/sidewalk on the fill section is degraded due to run-off from asphalt pavement across the steep side slope which discouraging pedestrians moving on the walkway, instead using the carriageway with vehicles in turn causing severe traffic accident.
Kosho River Bridge	241.75	* Kosho bridge is narrow and located in sharp reverse curves having a radius of 20m and 22m which in turn causing Over-turning and Head-on collisions of vehicles at the entrance, exit and on the bridge. * When approaching from Addis to the site, after the exit of the bridge, Bush and Trees grown on the back slope adjacent to the inner lane of the curve stationed between Km 241+881 to 241+932 obstructs distant vision to the bridge.
Bekere River Bridge	246.22	* The existing 6m Bekere River bridge is too narrow and located on sharp horizontal curve having radii of 26m which is a part of reverse curves. * When approaching from Addis to the bridge approach, the existing two retaining walls provided as barriers/guard rails are not connected even though there is steep side-slope on the right hand-side of the road.
Simini River Bridge	246.86	* The bridge is located in sharp horizontal broken-back curves having radii of 30.8m, 74m and 27.5m. * When approaching from Addis to the bridge approach, the road is consists of reverse curves and on adjacent to the inner lane of the first curve, there is hilly terrain with bush cover which obstructs distant sight to the bridge. * Adequate road warning sign is not provided such as steepness of the grade.
Shoshe	247.82	* When approaching from Addis to the site, there is a sharp horizontal curve having radii of 13.75m which is a part of reverse curves in combination with steep ascend of 5.832 % and hence the site is too difficult to tract the curve, especially for long public transportation buses and heavy Truck-trailers * There is no steel/masonry guard in the outer lane of the curve which alert and prevent the descending vehicles from run-off-the-road. * There is no curve and speed limit indicator sign on both approaches. * The existing widening provided in the inner lane of the curve for the purpose to widen the turning path for the descending vehicles has damaged which are causing falling of heavy vehicles.

Table 4.25: Observed Design Deficiencies on Black-Spot Areas on Gibe-Jimma Road

1	2	3
Sokoru Town	250	* When approaching from Addis, the road sections crossing Sokoru town has steep down-grade upto 6.692 % for the total length of town section which unintentionally leading to uncontrolled speed of vehicles causing due to inertia force resulting Vehicle-vehicle and Vehicle-pedestrian collisions. * The existing bridge found in the town at station Km 251+729 is narrow and it is difficult for fast drivers on descending direction to keep their vehicles on the road to prevent collisions of vehicles as well as intensive pedestrians walking on and approaches to the bridge especially during market day. * The 2m wide Shoulder/Sidewalks adjacent to the fill sections of some parts of the town has degraded due to scouring effect of run-off drained from the road and climbing effect of intensive pedestrian traffic to the carriageway since there is no ramp for pedestrians and animals.
Awano	254.1	* When approaching from Jimma direction, as the site is located in Broken-back curves having radii of 40m, 48m and 40m without tangent section in combination of steep downgrade of 7 %, no speed limit as well as curve indicator sign is provided on both approaches. * Back-slope of the road adjacent to the inner lane of the curves is covered with bushes and vegetable trees which obstructs distant sight causing sudden approach of the drivers which in turn resulting Over-turning, Head-on collisions and run-off the road of vehicles.
Birile River Bridge	255.13	* The existing Birile River bridge is too narrow and located in sharp curve having radii of 48m (a part of broken-back curves) has causing Over-turning on the bridge and Run-off-the-road of vehicles on its approach.
Kore River Bridge	256.8	* The existing Kore River bridge which is too narrow (6m) and located in sharp horizontal curve having radii of 69.392m (a part of approach reverse curves) has causing Over-turning on the bridge and Run-off-the-road of vehicles.
Teyar River Bridge	257.52	* Teyar River bridge is narrow and located in broken-back curve (C-curve) having radii of 35m and 100m with small tangent in between which has causing Over-turning on the bridge and Run-off the road of vehicles. * When approaching from Addis to the bridge site, silt deposition/mud flow has been occurring due to flooding during rainy season from the back-slope direction which in turn causing run-off the road of vehicles to the upstream/downstream of the bridge.

Table 4.25: Observed Design Deficiencies on Black-Spot Areas on Gibe-Jimma Road

3	4	14
Gilgel Gibe HEP Office	258	* As the area is Gilgel Gibe I Hydroelectric power camp with small village settlement around the office, no speed limit sign is provided. * The alignment of the area is sharp horizontal curve having radii of 74m and back slope adjacent to the inner lane of the curve is covered with resident fences and vegetable trees which obstructs distant sight.
Wuha Limat	262	* The road stretch crossing small rural village has consisting of steep downgrade of 6.516 % in combination with broken-back curves (C-curve) which are causing run-off-the-road of vehicles. * There is no road traffic sign of curve, steepness and showing village houses on both approaches.
Deneba River	264	* When approaching from Jimma to Deneba River bridge, the road stretch consisting of steep downgrade with reverse sharp horizontal curves in addition to narrow cross-section of the bridge. * The back-slope adjacent to the inner lane side of the curve is covered by Eucalyptus trees and Bushes are creating obstruction of distant vision to the bridge.
Deneba Town	265	* When approaching from Addis, the road sections crossing Deneba town has steep downgrade upto 6.776 % for the total length of the town. * In town sections of Deneba the shoulder/sidewalk on the fill section of the road has demolished due to run-off from Asphalt pavement across the steep side-slope which is discouraging pedestrians moving on the walkway which in turn causing severe traffic accident.
School Area	266	* As the location is town section and school area; students are vulnerable to road traffic accident. * Pedestrians are not using zebra crossings properly instead they use road section.
G/Gibe Bridge	290.3	* When approaching from Addis to the site, at the entrance to Gilgel Gibe bridge, there is a curve having radii of 100m without a guard-rail on the outer lane of the curve and hence causing Run-off-the-road of vehicles.
Beda Buna	348	* The road section is consists of steep downgrade of 7.865% in correspondence with series of reverse curves (including curve radii of 31m) which makes too difficult to the drivers to keep the balance of their vehicles in turn Run-off-the-road, Over-turning and Head collisions of vehicles resulting significant loss of human life and huge property damages. * The back-slope adjacent to the inner lane of the curves is covered with Bush and Trees obstructs distant vision which in turn leading to Head-on collision and Run-of-the-road.

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

Station in Km from A.A	Proposed Possible Engineering Interventions	
	Short-Term Engineering Interventions	Long-Term Engineering Interventions (Option-1)
1	2	3
194.5	* Providing warning message (i.e. condition of dangerness of forthcoming road) on wide board at the entry to the area, @ Km193+050 and Km 195+150 from Addis. * Bush and Trees found adjacent to the inner lane of the curve should be routinely cleared. * The damaged widening lane should be reconstructed as soon as possible with non-weathered basaltic stone since widening in the inner lane of the curve can reduce Head-on collisions as the vehicles on the inner lane can use the widened lane while making a turn instead of using the extra lane reserved for opposite traffic. * Provision of corrugated steel sheet guard rail on the outer lane of the curve is required. * Warning sign showing a curve should be provided before entering to the curve. * Speed-limit sign of 20 km/hr (as per the design i.e. 20-35 km/hr.) should be provided on both approaches to the site at appropriate location.	***** Re-alignment of the route should be required since the area is consists of high density of narrow bends of radii less than 40m (including curve radii of 13.75m) in correspondence with steep slopes of 5%-7%. .
201	* Appropriate road warning and information sign is required. * Clearing Bushes and Trees from adjacent to the inner lane of the curves routinely, hence it will improve the sight distance. * Clearing Brushes and Bushes from both sides of the shoulders timely in order to enable the pedestrians walk on the shoulders which in turn increasing the capacity of the roadway.	* Avoiding the sharp Curves located between station 201+001.407 - 201+347.035 and combining the remaining two disconnected curves located between station 200+916.833 - 201+404.170 together to have common PI so that flat curve with large radius can be achieved (i.e. Re-alignment is found to be necessary).

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

1	2	3
209.6	* Posting Speed-limit sign and other road warning sign is mandatory as the area is very dangerous. * Provision of about 100m long corrugated steel sheet guard rail on the outer lane of the curve is mandatory because of sharpness of the curve. * Trimming /removing objects, Bushes and Vegetable trees found on the back-slope adjacent to the inner lane of the curve is possible and can improve distant vision.	
212	* Providing speed-limit sign is mandatory. * Provision of guide post on the inner side of the curve.	
217	* Removing Eucalyptus trees and Bushes adjacent to the inner lane of the curve can improve distant vision. * Sign of sharp curve and narrow Bridge indicators should be installed on both approaches.	* Since the bridge is 2m span box-culvert which has 6.5m width, it should be widened to 8m-9m width. * When approaching from Addis, after exit from the bridge between station km 217+017 to 217+081 the approach road in the outer lane of the curve can be widened/shifted to the RHS of the road in order to reduce the sharpness of the curve and hence provide refugee area for sudden incoming vehicles.
221	* The unprotected gap between the preceding culverts and Getta bridge (between stations 220+884 to 221+000) should be provided with corrugated steel guard rails to protect run-off the road of vehicles and forewarn the drivers. * Installing speed limit and other road warning sign is mandatory as the area is very dangerous. * Corrugated steel sheet guard rail Provision of 100m long on the outer lane of curve is mandatory because of sharpness of the curve. * Trimming or removing objects on back slope is possible and can improve vision.	* In order to facilitate safe and straight entrance to the bridge, by eliminating series reverse curves (having radii of 169m, 107.5m,75m, 65m and 90m) found between stations 220+433 to 220+981, one common PI can be achieved by shifting the road to the LHS about to 30m from the existing road.

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

1	2	3
231.4	* Provision of speed-limit sign on both approaches to the bridge. * Removing Bushes and Trees adjacent to the inner lane of the curve so that sight distance can be improved. * Provision of traffic sign of narrow bridge ahead on both approaches and sharp curve indicator when approaching from Jimma	* In order to create straight and safe entrance to the bridge, the two curves found between station 231+200.623 to 231+543.351 together to have common PI so that one flatten curve with large radius can be achieved by shifting the road to the LHS to about 20m from the edge of existing road. * When approaching from Jimma to the bridge, the curve found between stations 231+654.850-231+722.560 can be eliminated by shifting the road to the RHS about 20m from the edge of the road.
234.2	* Smooth concrete ditch having sufficient drainage capacity should be provided on the cut section (LHS when approach from Addis) approximately from station 234+100 - 234+273 (inlet of 0.8m wide Pipe culvert).	
238	* From station Km 237+476 to 239+500 the road stretch should be provided with Road humps or Speed breakers painted white (preferably reflectorized) to make them visible at night and suitable road signs should also be placed to forewarn the drivers. * The shoulder/sidewalk of the roadway which has degraded should be reconstructed and supported by retaining wall in order to encourage the pedestrians moving on the walkway.	
241.75	* In order to improve the sight distance, the Bush and Trees growing adjacent to the inner lane of the curve should be cleared routinely.	* Avoiding those curves located between station 246+223.335 - 246+436.144 and combining the remaining two disconnected curves located between Station 246+180.400 - 246+497.525 together to have common PI so that flat curve with large radius can be achieved (i.e. Re-Alignment is found to be necessary).

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

1	2	3
246.22	* The existing two retaining walls provided as barrier/guard rail stationed between Km 245+915 to 245+996 should be connected by either masonry retaining wall or corrugated steel-sheet for the whole length of the gap to prevent run-off-the-road of vehicles.	* When approaching from Addis, since the construction of newly relocated bridge on the downstream side has completed, the road can be re-aligned/shifted to the left hand-side by avoiding the three curves (i.e. radii 200m, 155m and 60m) found between station Km 245+812 to 246+147 combining together to have common PI so that flat curve with large radius can be achieved.
246.86	* Road sign showing reverse curve should be installed in conjunction with bridge Sign. * Providing speed calming measures near the bridge site should be another option. * Removing sight obstruction object on the inner lane of the curve is possible so that sight distance is improved. * Installing wide board consisting of information message about the dangerness of the road and other warning sign close to the area should be another option to minimize the traffic accident.	* Since the bridge re-location is under construction, when approaching from Addis to the bridge site, the road should be re-aligned/shifted to the LHS for about 40m approximately for 80m length in order to minimize the sharpness of the approach curve.
247.82	* Installing wide board consisting of information message about the dangerness of the road and other warning sign close to the area should be another option to minimize the traffic accident. * Removing sight obstruction objects found adjacent to the inner lane of the curve is possible so that sight distance can be improved. * Steel guard rail should be provided on both outer and inner lane of the curve. * Curve and speed limit indicator sign could be posted in both approach. * The damaged widening should be replaced as soon as possible with basaltic rubble masonry which can withstand high friction of heavy loaded Trucks and Truck-Trailers in the inner lane side of the curve.	* Re-alignment of the route between Saja to Sokoru town should be required.

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

1	2	3
250	* From km 250+000 - 252+400 should be provided with Road humps or Speed breakers painted with white paint (preferably reflectorized) to make them visible at night and suitable road signs should also be placed to forewarn the drivers. * The shoulder part of the roadway which has demolished should be reconstructed/replaced and supported by constructing retaining wall.	* Since the bridge is 3m clear span box-culvert, it can be widened without traffic interruptions during upgrading in order to accommodate both vehicles and pedestrians safely.
254.1	* Traffic sign of speed-limit and sharp curve indicator should be posted on both approaches to the site. * Provision of widening with non-weathered basaltic stone in the inner lane side of the curve can reduce Head-on collisions of vehicles. * Provision of Steel barrier adjacent to the outer lane of the curve from station Km 254+072 to 254+125 to prevent run-off-the-road of vehicles moving to descending direction and residential houses from collision. * Bushes and Trees found adjacent to the inner lane of the curve should be cleared timely.	
255.13	* Provision of speed-limit and road traffic sign which disallows overtaking near the bridge should be introduced.	* Re-location of the bridge at the downstream side to about 8m from the edge of existing bridge and re-alignment of the approach road should be required to prevent severe traffic accident.
256.8	* Provision of speed-limit and road traffic sign which disallows overtaking near the bridge should be introduced.	* Since re-location and construction of the new bridge at the downstream side has completed, the approach road should be re-aligned as soon as possible to prevent severe traffic accident.
257.52	* Drainage ditch having enough accommodation capacity, made of reinforced concrete should be provided on the back-slope side to prevent Run-off the road of vehicles resulting from sliding capability of silt deposition/mud flow.	* In order to have enough Bridge width and straight approaches road, the Bridge can be re-located to the downstream side to about 30m from the edge of the road/bridge.

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

1	2	3
258	* Provision of Speed-limit and road sign which disallows overtaking should be introduced. * Curve widening in the inner lane side should be required in order to facilitate distant vision and to keep free road right of way. * Removal of distant sight obstruction objects on the back-slope of the road. * Provision of animal sign is also mandatory as the area occupied by lots of household animals.	* No need of road re-alignment as the accident frequency is very minimum.
262	* Provision speed-limit sign is mandatory as the location is small village area. * Road traffic sign showing curvedness, steepness and village houses should be provided before entry to the village.	* Avoiding the curves located between station Km 261+833.988 to 262+176.979 combining together to have a common PI so that one flat curve with large radius can be achieved (i.e. Re-alignment is found to be necessary).
264	* Warning and information signs describing the dangerness of the road ahead should be installed at the exit of Deneba town on wide board. * Removing road side obstruction objects and widening the inner lane of the curve can improve sight distance to the bridge.	* When approaching from Jimma to Deneba River bridge, by trimming the back-slope between station Km 263+849.248 to 264+051.677 to RHS for at least 30m, re-locating bridge and re-alignment of its approach on the upstream side, straight bridge approaches can be achieved.
265	* From km 265+000 - 266+560 could be provided with Road humps or Speed breakers painted with white paint (preferably reflectorized) to make them visible at night and suitable road signs should also be placed to forewarn the drivers. * The shoulder/sidewalk of the roadway which has degraded should be reconstructed/replaced and supported by constructing retaining wall in order to encourage the pedestrians moving on the walkway.	

Table 4.26: Engineering Interventions on Black Spot Areas on Gibe-Jimma Road

1	2	3
266	* Road signs showing students' picture should be provided. * Road Sign which disallows overtaking should also be provided. * Closing road side with steel guard rail should be better option.	** Pedestrian over-pass bridge around the school area should be an option for the future.
290.3	* When approaching from Addis to the bridge site the Corrugated steel sheet guard-rail should be provided from station 290+111 to 290+229 on the outer lane side of the curve to prevent the vehicles from Run-off the road.	
348	* In order to forewarn the incoming drivers, the solar powered, soundless traffic light alarm should be installed at station km 347+300 and 349+000 followed to warning message of 8 % steepness and dangerness of the road ahead on wide steel-sheet board can reduce the traffic crash significantly. * Bush and Trees found on the back-slope adjacent to the inner lane of the curve should be routinely cleared.	* In order to have a common PI together, removing the reverse curves having radii of 31m, 140m, 225m, 210m & 85m found between station 347+896 - 348+368 and hence the curvedness can be improved by shifting the road to the RHS (when approaches from Addis). * Re-alignment of the road should be promising.

Long-Term Engineering Interventions (Option-2): New Route Selection

Based on the Results and Discussions carried out in chapter four, the road section from Gibe River Bridge to Deneba (Station km 185+700 to km 266+000) concluded as Black-spot road segment by the writer of this research since it has significant deficiencies on cross-section, horizontal and vertical alignment. To alleviate the adverse effects of these deficiencies on the road users as well as on the government, short term and long term interventions were recommended. Under the long term interventions, option-2 is the selection of new route for Gibe Bridge-Deneba and Saja-Sokoru Town were conducted by least cost path method based on ArcGIS version 10 computer application software. For this software analysis, slope map and stream-order map derived from spatial data named as digital elevation model (DEM) of Ethiopia were used as an input for the new route selection and in weighted overlay table, the influence factor given for Reclassed slope was considered to be 0.6 (60%) while for stream-order was 0.4 (40%). The geographic coordinates of the newly selected route are as tabulated in Table 4.27 and 4.28.

Table 4.27: Proposed New Gibe Bridge-Abelti Least Cost Path Route Geographic Coordinates

Serial No.	Decimal Degrees (DD)		UTM Coordinates in Meters		Remark
	Longitude	Latitude	Northing (Y)	Easting (X)	
1	37.579	8.226	909560.3886	343478.91	
2	37.578	8.226	909560.7798	343368.7396	
3	37.578	8.225	909450.1941	343368.3469	
4	37.577	8.225	909450.5855	343258.1762	
5	37.577	8.224	909339.9998	343257.7832	
6	37.576	8.224	909340.3914	343147.6122	
7	37.576	8.223	909229.8057	343147.219	
8	37.575	8.223	909230.1975	343037.0476	
9	37.575	8.222	909119.6118	343036.6542	
10	37.575	8.221	909009.026	343036.2608	
11	37.575	8.22	908898.4402	343035.8675	
12	37.575	8.219	908787.8545	343035.4742	
13	37.575	8.218	908677.2687	343035.0809	
14	37.575	8.217	908566.683	343034.6877	
15	37.574	8.216	908456.489	342924.1212	
16	37.574	8.215	908345.9032	342923.7279	
17	37.574	8.214	908235.3175	342923.3345	
18	37.574	8.213	908124.7317	342922.9413	
19	37.574	8.212	908014.1459	342922.548	
20	37.574	8.211	907903.5602	342922.1548	
21	37.574	8.21	907792.9744	342921.7617	
22	37.574	8.209	907682.3886	342921.3686	
23	37.574	8.208	907571.8029	342920.9756	
24	37.574	8.207	907461.2171	342920.5826	
25	37.574	8.206	907350.6314	342920.1896	
26	37.574	8.205	907240.0457	342919.7967	
27	37.574	8.204	907129.4599	342919.4039	
28	37.574	8.203	907018.8742	342919.011	
29	37.573	8.202	906908.6799	342808.441	
30	37.573	8.201	906798.0942	342808.0481	
31	37.573	8.2	906687.5084	342807.6551	
32	37.573	8.199	906576.9227	342807.2622	
33	37.573	8.198	906466.3369	342806.8694	
34	37.573	8.197	906355.7512	342806.4766	
35	37.573	8.196	906245.1655	342806.0838	
36	37.573	8.195	906134.5797	342805.6911	
37	37.573	8.194	906023.994	342805.2985	
38	37.573	8.193	905913.4083	342804.9059	
39	37.573	8.192	905802.8226	342804.5133	
40	37.573	8.191	905692.2369	342804.1208	
41	37.572	8.19	905582.0423	342693.5477	

Table 4.27: Proposed New Gibe Bridge-Abelti Least Cost Path Route Geographic Coordinates

Serial No.	Decimal Degrees (DD)		UTM Coordinates in Meters		Remark
	Longitude	Latitude	Northing (Y)	Easting (X)	
42	37.572	8.189	905471.4566	342693.1551	
43	37.572	8.188	905360.8708	342692.7624	
44	37.572	8.187	905250.2851	342692.3698	
45	37.572	8.186	905139.6994	342691.9773	
46	37.572	8.185	905029.1136	342691.5848	
47	37.572	8.184	904918.5279	342691.1923	
48	37.572	8.183	904807.9422	342690.7999	
49	37.572	8.182	904697.3565	342690.4075	
50	37.572	8.181	904586.7708	342690.0152	
51	37.572	8.18	904476.1851	342689.623	
52	37.572	8.179	904365.5994	342689.2308	
53	37.572	8.178	904255.0137	342688.8386	
54	37.571	8.178	904255.4046	342578.6547	
55	37.571	8.177	904144.8188	342578.2623	
56	37.571	8.176	904034.2331	342577.8699	
57	37.571	8.175	903923.6474	342577.4776	
58	37.571	8.174	903813.0617	342577.0854	
59	37.571	8.173	903702.476	342576.6932	
60	37.571	8.172	903591.8903	342576.301	
61	37.571	8.171	903481.3046	342575.9089	
62	37.571	8.17	903370.7189	342575.5168	
63	37.571	8.169	903260.1332	342575.1248	
64	37.571	8.168	903149.5475	342574.7329	

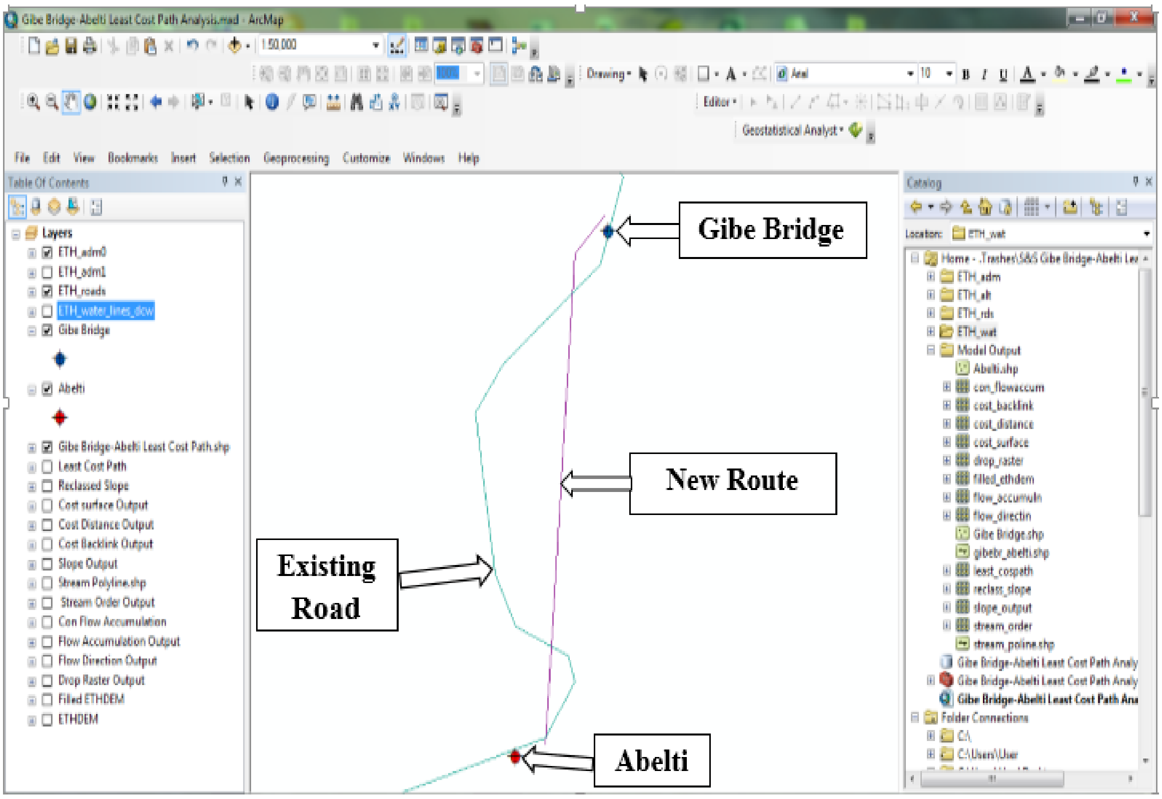


Figure 4.1: Gibe Bridge-Abelti Town Least Cost Path

Table 4.28: Proposed New Saja-Sokoru Least Cost Path Route Geographic Coordinates

Serial No.	Decimal Degrees (DD)		UTM Coordinates in Meters		Remark
	Longitude	Latitude	Northing (Y)	Easting (X)	
1	37.437	7.968	881085.9935	327724.5803	
2	37.437	7.967	880975.4023	327724.162	
3	37.437	7.966	880864.8111	327723.7438	
4	37.437	7.965	880754.2199	327723.3256	
5	37.437	7.964	880643.6287	327722.9075	
6	37.437	7.963	880533.0375	327722.4894	
7	37.437	7.962	880422.4463	327722.0714	
8	37.437	7.961	880311.8551	327721.6534	
9	37.437	7.96	880201.264	327721.2355	
10	37.437	7.959	880090.6728	327720.8177	
11	37.437	7.958	879980.0816	327720.3999	
12	37.437	7.957	879869.4905	327719.9821	
13	37.437	7.956	879758.8993	327719.5644	
14	37.437	7.955	879648.3082	327719.1467	
15	37.437	7.954	879537.717	327718.7291	
16	37.437	7.953	879427.1259	327718.3116	
17	37.437	7.952	879316.5348	327717.8941	
18	37.437	7.951	879205.9436	327717.4767	
19	37.437	7.95	879095.3525	327717.0593	
20	37.437	7.949	878984.7614	327716.6419	
21	37.437	7.947	878763.5792	327715.8074	
22	37.437	7.946	878652.9881	327715.3902	
23	37.437	7.945	878542.397	327714.9731	
24	37.437	7.944	878431.8059	327714.556	
25	37.437	7.943	878321.2148	327714.139	
26	37.437	7.942	878210.6237	327713.722	
27	37.437	7.941	878100.0326	327713.3051	
28	37.437	7.94	877989.4416	327712.8882	
29	37.437	7.939	877878.8505	327712.4714	
30	37.437	7.938	877768.2594	327712.0546	
31	37.437	7.937	877657.6684	327711.6379	
32	37.437	7.936	877547.0773	327711.2213	
33	37.437	7.935	877436.4863	327710.8047	
34	37.437	7.934	877325.8952	327710.3881	
35	37.436	7.934	877326.3106	327600.1315	
36	37.436	7.933	877215.7195	327599.7147	
37	37.435	7.933	877216.1352	327489.4578	
38	37.435	7.932	877105.544	327489.0408	
39	37.434	7.932	877105.9599	327378.7836	
40	37.434	7.931	876995.3687	327378.3664	
41	37.433	7.931	876995.7847	327268.1089	

Table 4.28: Proposed New Saja-Sokoru Least Cost Path Route Geographic Coordinates

Serial No.	Decimal Degrees (DD)		UTM Coordinates in Meters		Remark
	Longitude	Latitude	Northing (Y)	Easting (X)	
42	37.433	7.93	876885.1935	327267.6915	
43	37.432	7.929	876775.0185	327157.016	
44	37.431	7.929	876775.435	327046.7578	
45	37.431	7.928	876664.8436	327046.34	
46	37.43	7.928	876665.2603	326936.0815	
47	37.43	7.927	876554.669	326935.6634	
48	37.429	7.926	876444.4945	326824.9863	
49	37.428	7.926	876444.9116	326714.7272	
50	37.428	7.925	876334.3201	326714.3087	
51	37.427	7.925	876334.7375	326604.0493	
52	37.427	7.924	876224.1459	326603.6306	
53	37.426	7.923	876113.9719	326492.9519	
54	37.425	7.923	876114.3897	326382.6918	
55	37.425	7.922	876003.7981	326382.2727	
56	37.424	7.921	875893.6244	326271.5929	
57	37.423	7.921	875894.0426	326161.3322	
58	37.423	7.92	875783.4509	326160.9127	
59	37.422	7.919	875673.2776	326050.2318	
60	37.421	7.919	875673.6962	325939.9705	
61	37.421	7.918	875563.1044	325939.5505	

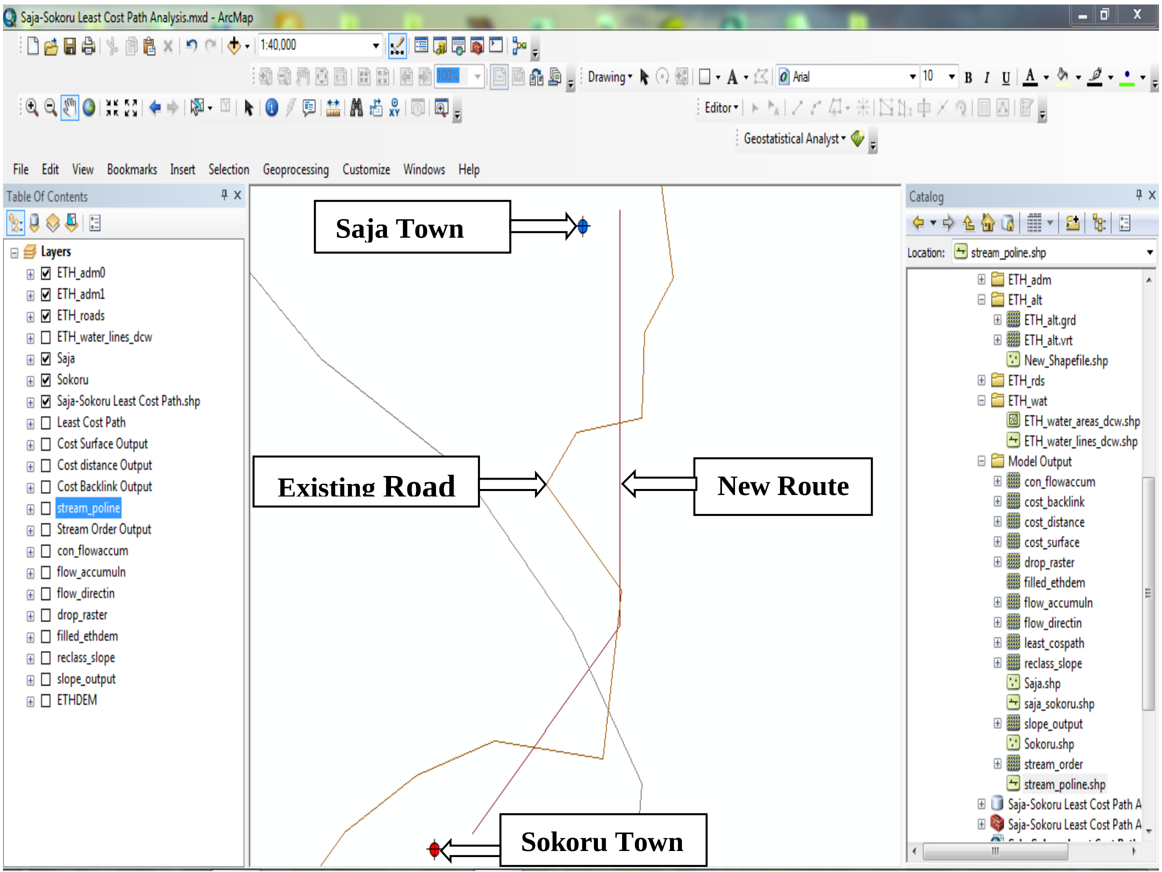


Figure 4.2: Saja-Sokoru Town Least Cost Path

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Many developed countries have discovered that even highway and traffic schemes were professionally designed to the latest standards, they could still lead to unnecessary accidents. A common finding was that traffic crashes tended to occur at the ends of schemes where a transition to a road of different standards, or related to pedestrians or other vulnerable road users whose particular needs had not been given sufficient attention. These design can best be reduced or eliminated by an independent road safety specialist reviewing the designs at various stages in the design process of new as well as rehabilitation of existing road projects.

Based on the results and findings of this thesis, even though it was found out that the road section from Gibe River Bridge to Deneba Town was identified as deficient related to highway route location and geometric design attributes and hence a major Black-spot Road Segment, the assessment were also included the road segment from Addis to Gibe Bridge and Deneba to Jimma Town since they are a part of a highway under this study because their contributions to road traffic crash are interrelated. In general, based on the comparative analysis between the road segments of Addis-Gibe River Bridge, Gibe Bridge-Deneba and Deneba to Jimma town, the result indicates that:

1. Addis Ababa to Gibe Bridge road segment has lesser deficiencies related to route and geometric design attributes than Gibe Bridge to Deneba road segment since there is no switch-back horizontal curves (radii below 20m) as well as horizontal curves having radii below 40m, instead in this road segment found, 90.1% of the horizontal curves have radii above 125m, from the total length 175.03 km of the road section, the curve length accounts only 27.48 km (15.7%), 94.42% of vertical gradient fall into the category of 0%-5% grade and it has road traffic crash rate of 1.44 for Addis to Woliso (including traffic crash in Sebeta City) and 0.73 for Woliso-Gibe Bridge.
2. Gibe Bridge-Deneba road segment has significant deficiencies related to highway route location and geometric design attributes when compared to Addis to Gibe Bridge and Deneba to Jimma road section since it composed of the existence of 6m and 6.5m wide narrower road section, the curve length accounts 40.9 km

(50.9%) while the tangent length accounts 39.5 km (49.1%), the existence of 94.74% of the narrowest curves (radii less than 40m) and all of the seven Switch-back curves (radii of 20m or less, with a minimum of 13.75m), 41.5% of the vertical alignment fall into the category of 5%-10% while 58.7% fall into 0-5%.

3. Gibe Bridge to Deneba road Segment is concluded as a black-spot road segment since the traffic crash rate on this road segment has scored the greatest value of 1.57 followed by Addis to Woliso 1.44 (including traffic crash in Sebeta city), Woliso-Gibe Bridge 0.73, and Deneba-Jimma road section has scored 1 with property damages cost of 179,343.49 ETB/Km of road due to road traffic crash.
4. Gibe River Bridge to Deneba Road Segment has been exposed the government to a huge cost of ETB 41,673,094.63 in four years of 2012-2015 G.C for relocation or reconstruction of highway drainage crossing structures and its approaches road because of those Bridges and Culverts were existed in sharp horizontal curves and hence a place of black-spot areas resulting loss of human life and huge property damages.
5. Deneba to Jimma road Segment has less deficiencies related to route and geometric design attributes when compared to Gibe Bridge to Deneba road section since there is no switch-back horizontal curves (radii below 20m) as well as horizontal curves having radii below 40m and from the total length of the road segment 70.34 km (excluding the alignment road), the curve length accounts 24.614 km (35%) while the tangent (straight) sections accounts 45,726 km (65%) and 87.9% of vertical gradient fall into 0%-5% with traffic crash rate of 1, and property damages cost of 45,102.91 ETB/Km of road due to road traffic crash.
6. The existing Addis Ababa-Jimma Road, especially the road segment from Gibe Bridge to Deneba Town, lacked most of the modern highway location and geometric design attributes desirable for present day traffic volume, large size, heavy weight and high-speed traffic and hence upgrading should be required based on further traffic volume projections for the design period to be intended.

5.2 Recommendations

Road traffic crashes are caused or influenced by a number of factors and the one that is most prevalent is human behavior. Engineering design is, however, also important as it should accommodate a wide range of human behavior and encourage safer use of the roads. Sadly, this is not always the case and inappropriate engineering design can be a factor in a high percentage of accidents. Indeed, engineering features are often easier and cheaper to change than human behavior, and can have an immediate effect.

To address similar objectives on Addis Ababa - Jimma road especially on Gibe Bridge to Deneba road segment, based on the findings of this research, the following recommendations are forwarded to the key role players pointed below in order to apply engineering interventions.

Client/ERA

Client/ERA is one of the most important party who invest money for the realization of design and construction, upgrading and maintenance of road projects. The following recommendations are forwarded to ERA/Client.

1. ERA should conduct yearly traffic count by dividing Addis-Jimma route into the road segment Addis-Alemgena, Alemgena-Woliso, Woliso-Wolkite, Wolkite-Gilgel Gibe and Gilgel Gibe-Jimma since these towns are a junctions of at least two or more trunk/link roads;
2. The road segment from Sebeta (Dima) to Tulu Bolo, the full section of the carriageway should be provided with asphalt concrete overlay to avoid unevenness in longitudinal and transverse profile rather than applying patching of cracked parts of the pavement only;
3. Widening of the narrower traffic lanes, shoulders and parking lanes for the full towns section on the road should be implemented based on further analysis of traffic volume and as per ERA design standard;
4. Relocation of the existing Italian era narrow bridges which are mostly fitted with the existed carriageway width of approaches road and located in sharp horizontal curves in correspondence with steep gradient especially on Gibe Bridge to Deneba road segment;
5. Provision of speed-brakers followed to suitable traffic signs/warning message on wide steel sheet board to forewarn the drivers on the tangent section of horizontal curves above 4km length and in the towns with long steep gradient on Addis-Jimma road;
6. Provision of solar-powered warning lights on both approaches of black-spot road stretches followed by warning messages about the road ahead on wide steel board;
7. Trimming of natural and manmade distant sight obstructions found adjacent to the inner lane of the curves and on the shoulders timely as the required level;

8. Transitional speed limit zones should be adopted on the road approaches to major towns found along Addis-Jimma road before the drivers entering the towns with 30km/hr of speed;
9. Evaluation of possible alternative routes for the black-spot road stretches to minimize occurrence of severe road traffic crashes, drainage crossing structures re-location/re-placement costs and vehicle operation and maintenance costs;

Contractors

Contractors are one of the stakeholders who participate directly on the construction and upgrading and rehabilitation and maintenance of road projects; accordingly the following recommendations are forwarded to the contractors.

1. During implementations of low-cost engineering interventions priority should be given to an areas of critical black-spot areas to minimize road traffic crashes;
2. The contractors should suggest on possible and alternative engineering interventions for black-spot road segment as well as particular areas during their way of periodic and routine road maintenance activities;

Consultants

The consultants is one of the key role players in designing and supervision of road projects. The following recommendation are forwarded to the consultants.

1. The consultants should comply the required analysis of the geometric design attributes with ERA and AASHTO design standard and the adequacy for present traffic accommodation capacity of the existing Addis Ababa-Jimma road;

Government

The government is one of the key role players in enforcement of traffic law and traffic management system; accordingly the following recommendations are forwarded to the government authorities.

1. Implementation of strict speed limit control as per the design of the road, by using advanced vehicles speed measuring electronic devices like portable or vehicle mounted radar system on the road segment;
2. The Traffic Polices crash record data should be recorded in such a manner to include Kebele/PA, special/particular name and post (km) of crash area.
3. Creation of continuous awareness on pedestrians regarding road usage especially in towns, villages and school areas.

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APPENDIXES

Table 2-1: Design Standards vs. Road Classification and AADT

Road Functional Classification	Design Standard	Design Traffic Flow (AADT)*	Surface Type	Width (m)		Design Speed (km/hr.)				Urban/Peri-Urban
				Carriageway	Shoulder	Flat	Rolling	Mountainous	Escarpment	
TRUNK	DS1	10000–**15000	Paved	***Dual 2 x 7.3	See T.2-2	120	100	85	70	50
LINK	DS2	5000–10000	Paved	7.3	See T.2-2	120	100	85	70	50
	DS3	1000–5000	Paved	7.0	See T.2-2	100	85	70	60	50
MAIN ACCESS	DS4	200–1000	Paved	6.7	See T.2-2	85	70	60	50	50
COLLECTORS	DS5	100– 200	Unpaved	7.0	See T.2 -2	70	60	50	40	50
FEEDER	DS6	50–100	Unpaved	6.0	See T.2-2	60	50	40	30	50
	DS7	30–75	Unpaved	4.0	See T.2-2	60	50	40	30	50
	DS8	25–50	Unpaved	4.0	See T.2-2	60	50	40	30	50
	DS9	0–25	Unpaved	4.0	See T.2-2	60	40	30	20	40
	DS10	0–15	Unpaved	3.3	See T.2-2	60	40	30	20	40

* The design two-way traffic flow is recommended to be not more than one Design Standard step in excess of the first year AADT (excluding DS7). ** For traffic volume more than 15000 a different design approach should be followed. *** The width of each lane is 3.65m

Table 2-2: Shoulder Widths

Design Standard	Rural Terrain/Shoulder Width (m)				Town Section Widths (m)			
	Flat	**Rolling**	**Mountainous**	**Escarpment**	**Shoulder**	**Parking Lane*** **	**Foot way**	**Median[!]**
DS1	3.0	3.0	0.5 – 2.5	0.5 – 2.5	n/a	3.5	2.5 (min)	5.0 (min)
DS2	3.0	3.0	0.5 – 2.5	0.5 – 2.5	n/a	3.5	2.5	Barrier[!]
DS3	1.5 - 3.0++	1.5 - 3.0++	0.5 – 1.5	0.5 – 1.5	n/a	3.5	2.5	n/a
DS4	1.5	1.5	0.5	0.5	n/a	3.5	2.5	n/a
DS5[*]	0.0	0.0	0.0	0.0	n/a	3.5[+++]	2.5	n/a
DS6**	0.0	0.0	0.0	0.0	n/a	3.5[+++]	2.5	n/a
DS7	1.0 (earth)	1.0 (earth)	1.0 (earth)	1.0 (earth)	n/a	n/a +	n/a +	n/a
DS8**	0.0	0.0	0.0	0.0	n/a	n/a +	n/a +	n/a
DS9**	0.0	0.0	0.0	0.0	n/a	n/a +	n/a +	n/a
DS10**	0.0	0.0	0.0	0.0	n/a	n/a +	n/a +	n/a

* Shoulders included in the carriageway width given in Table 2-1
** Shoulders included in the carriageway width given in Table 2-1
*** To be provided where urbanization requires this facility
+ Where these classes of roads pass through urban areas, the road shall be designed to Standard DS6
++ The actual shoulder width provided shall be determined from an assessment of the total traffic flow and level of non-motorized traffic for each road section
+++ Depending on the development of the town & Includes a shoulder! Median with trees (DS1) is allowed for cross section shown in the table i.e. 2lane +parking lane + Footway if otherwise the median should be a covered and an open one without trees or a lower width of a median barrier shall be designed . Similarly for DS2 Roads in the town section i.e. one lane + parking lane +footway should have a covered median with no trees or otherwise a lower width of a median barrier should be designed.