



**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES**

**TRUCK OVERLOAD FINE RATIONALIZATION ON  
ETHIOPIAN PRIMARY ROADS  
A CASE STUDY ON ADDIS ABABA -ADAMA EXPRESSWAY**

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Addis Ababa University  
In partial fulfilment of the requirements for the Degree of  
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(Road and Transport Engineering)

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## ABSTRACT

The increasing economic activities in recent years in Ethiopia have increased the movement of freight activities on major roads. The need for reducing cost of transportation and transporters' efforts to make more profit by transporting heavier load have made overloading common on major freight road corridors. While uncontrolled growth in loads and volumes of heavier trucks may be beneficial to transporters, overloading however brings structural deterioration of bridges, premature pavement damage, increase in road accidents, increased air pollution, traffic congestion etc. Literatures recommend for effective enforcement and rational fine to be used in order to protect road infrastructures and sustain their serviceability. Ethiopian axle load limit regulation criminalizes overloading and provides power to concerned government body to lay overload fine at local courts nearby weighing station. In this regard, it was observed that the fine currently established by courts lacks rationality and effectiveness in preventing overloading.

The purpose of this thesis is to establish rational overload fine and compare with court-imposed overload fines. The research investigates relationships between traffic under different overloading and corresponding economic impacts on flexible pavement in terms of earlier intervention, maintenance costs and related vehicle operating costs (VOCs) and travel time costs to road users. Using the Highway Design and Management software (HDM 4 Version 1.1) life cycle programme analysis was done considering five road sections under this case study of the Addis Ababa – Adama Road link. The results of the analysis showed that, with optimum maintenance interventions on most road sections, the economic impact per axle was higher for higher overload cases. Statistical comparison between rationalized overload fines and court-imposed overload fines also showed a significant variation in respect of individual fines. Based on samples of overloaded trucks, the court-imposed gross revenue was found to be less than what could have been collected using rationalized fines.

In view of the foregoing, the study recommends rational fine to be introduced and the responsibility be transferred from local courts to the road network management agency. Revenue collected through rational overload fine will be used as cost recovery for road maintenance works and for the management of the weighing stations. The rational overload fine penalty also has to be supported with intensive enforcement using fixed and mobile weighing stations to prevent overloading.

This study is expected to lay a foundation for scientific approach of determining overload charges in Ethiopia and beyond. The procedure could also be used in special permits considering economic impact, including bridge damage costs and other service charges. For the purposes of effectiveness of the new approach of rational revenue generation and road infrastructure sustainability, overload fine structures must be updated regularly using current road and traffic data, and other relevant assumptions which were not considered in this study.

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## ACRONYMS

AAAEW:	Addis Ababa - Adama Expressway
AACRA:	Addis Ababa City Roads Authority
AADT:	Average Annual Daily Traffic
AASHTO:	American Association of State Highway and Transportation Officials,
BOT:	Build Operate and Transfer
BES:	Beijing Expressway Supervision
CBR:	California Bearing Ratio
CCCC:	China Communications Construction Company
COMESA:	Common Market for Eastern and Southern Africa
DB:	Design Build
ECOWAS:	Economic Community of West African States
EAC:	East African Community
ERA:	Ethiopian Roads Authority
ESA:	Eastern and Southern Africa
ESAL:	Equivalent Single Axle Load
ETRE:	Ethiopian Toll Roads Enterprise
ETB:	Ethiopian Birr
GVM:	Gross Vehicle mass
GVW:	Gross Vehicle Weight
HDM III:	Highway Design and Maintenance Model
HDM 4;	Highway Design and Management Model
HMAM:	High Modulus Asphalt Macadam
IRI:	International Roughness Index
LEF:	Load Equivalence Factor
NPV:	Net Present Value
PCI:	Pavement Condition Index
PI:	Plasticity Index
PSI:	Present Serviceability Index
PMS:	Pavement Management System

RMMS: Road Maintenance and Management System  
SATCC: Southern Africa Transport and Communications Commission  
SADC: Southern Africa Development Community  
SSATP: Sub-Saharan African Transport Policy Program  
SWK: Scott Wilson Kirkpatrick  
USA: United States of America  
VOC: Vehicle Operating Cost  
VAA-ADEW: Vehicle Fleet for Addis Ababa Adama Expressway

# 1. INTRODUCTION

## 1.1. Background

Truck overloading causes rapid deterioration of road infrastructures leads to earlier and more frequent maintenance interventions. Rapid road deterioration increases vehicle operating and travel time costs. It also forces the road authority to remedy the damage through rehabilitation/reconstruction at an earlier date than would have been less likely without overloading.

In order to prevent the early damage of the road infrastructure, countries usually impose axle load limits. These limits are meant to ensure that roads last for their full design lives with normal maintenance expenditures. In addition, specified limits are also necessary to ensure a level playing field between benefiting transporters and improving road safety. Once the axle load limits are set, road users should respect enforcement. Fixed Weighing Stations should be placed at the required locations for this purpose. However, it should be understood that heavy freight transport vehicles usually violate the allowable load limit.

Ethiopian Council of Minister's Regulation N° 11 (1990) sets vehicle size and weight & axle load limits. The regulation criminalizes overloading and provides the enforcing authority to take to local courts those that violate the regulation. However, the fines imposed for overloading are not based on damage done by the vehicle on the road pavement and the corresponding profit made by the hauler in transporting the extra load. It suggested that mostly, court-imposed fines do not have significant effect on discouraging overloading. Generally, the income from fines through local courts and finally to central government accounts is not directly accessible for road maintenance purposes and neither sufficient to mend the damage.

It is proposed that overloading be decriminalized, removed from court systems and handled administratively. Through administrative approach, overload fee that commensurate actual damage due to overloading is determined and fines settled at weighing stations. During this study, it was not possible to find any study conducted regarding overload control management in Ethiopia. However, overloading studies recommend for establishment of a rational overload fee that reflect the actual damage of the road pavement and be supported through effective administrative enforcement. Fixed inspection stations, in combination with portable weighing scales, are recommended for proper monitoring of large truck operations.

Once the fee schedule is prepared, overloaded vehicles will have to pay specified fees at the weighing stations that help to generate enough revenue to compensate damage done to pavements. This method also creates an opportunity for the private sector to take part in axle load management stations. However, the fee schedules need to be regularly updated based on current data within the road network considered.

## **1.2. Purpose of the Thesis**

The purpose of this thesis is to determine rationalised overload fine (price/axle overload/km) considering the economic impact of overloaded trucks and costs of weighing stations. The study also compares rational overload fine with current court-imposed overloading fee and propose rationalised overload fine to be applied to protect the road infrastructure.

The study uses truck overload patterns of the subject road (Addis Ababa – Adama road link) to identify overloaded cases with different rates of overloading. The study analyses the relationship between identified overloaded cases and corresponding pavement performances and optimum interventions required at different sections of the road link under consideration with subsequent assignment of different charges to different rates of overloading by analysing the corresponding economic impacts on the road pavement.

Indicators of economic impacts of overloaded trucks are many; however in this study, increase in pavement roughness (IRI) with corresponding VOCs, travel time costs and costs related to optimum maintenance interventions required to sustain the road standard were considered. The combined effects in terms of changes in costs and benefits were then discounted and aggregated into a common unit or net present value (NPV), which was used as an indicator of economic impact due to overloading.

Costs of weighing stations, including initial investment and running cost were also discounted and aggregated and equally distributed to all overloaded trucks in determining the final rational overload fine structure.

## **1.3. Statement of the Problem**

Overloading is criminalised in Ethiopia and overloaded truck operators pay fines specified by a local court nearby a weighing station where the fines are based on cumulative of extra weight measured in quintals of overloaded axles of overloaded vehicles. Usually, extra weights are adjusted or unloaded at the weighing station, according to legal limit, before allowing overloaded truck continues its trip. There are several problems associated with the management of overloaded trucks in Ethiopia; however, the main focus of this study is regarding two problems related with overload fines.

Firstly, overload charges imposed by court of law are laid based on factors that have no relation to the damage to road infrastructure and benefits of extra weights to transport operators. The rational overload fine structure (fee/ axle overload per kilometre) that takes into account rate of overloading and its economic impact is unknown. As a result, different judges lay different fines for the same rate of overloading. The lack justification and consistency makes overload fines ineffective on preventing overloading.

Secondly, all overload fines are paid to a local court account and the revenue collected is not used as a cost recovery to the road fund, which negatively affects sustainability of road infrastructure. In relation to this, the court procedure requires time from hours to days to complete the fine settlement process that depend on several factors related to system and vehicle operators themselves, which results in huge loss to transporters because of unnecessary time lost at local courts. For this and other reasons, many drivers usually avoid paying charges on the same day which is a loss of time value of money.

#### **1.4. Research Question**

The following questions are raised in the study:

- What is the rational overload fine structure (fine per axle overload per kilometre)?
- Is the current court procedure fair and does it guarantee reasonable protection of the road infrastructure?

#### **1.5. Organization of the Research**

The Research is divided into seven chapters. Chapter 1 discusses the introductory part of the research followed by Chapter 2 which deals with literature review. Chapter 3 formulates methodology while Chapters 4 deals with Overload management in Ethiopia and statistical data of weighing stations; Chapter 5 presents data collection, analysis, results and discussions of case study (Addis Ababa-Adama expressway); Chapter 6 presents conclusions and recommendations. Finally, Chapter 7 proposes future research areas.

## 2. LITERATURE REVIEW

### 2.1. Introduction

Road infrastructure represents huge investments for any country. To protect these assets against overloading, individual countries have regulations for permissible axle loads and vehicle dimensions. However, transport operators tend to overload to reduce their running costs and overhead for freight transport regardless of damaging impacts of overloading. Overload charges are laid by court are usually low compared with the damage done by the vehicle on the road and the higher revenue made by the hauler in transporting a heavier load. This requires determining rationalised overload fine that compensate pavement damage and other costs associated with overloaded traffic.

It should be noted that no direct literature regarding overloaded truck fine in Ethiopia was available. Consequently; books, journals, relevant reports related to overloading were considered for review.

The literature review is organised into sections, which includes consideration of traffic in pavement design, reasons and impacts of overloading, recommended solutions to prevent overloading and determination of economic loss due to overloading and overload charge. A review is also made on using pavement management system specially HDM-4 road deterioration model which is applied in Ethiopia.

Overloading is considered as common problem in both developed and developing countries. However, the problem is higher in developing countries with weak highway management system and poor control mechanisms. Proposed solutions to prevent overloading include the necessity of establishment of rational overload fine that commensurate actual pavement damage costs. This requires analysing economic loss due to overloading and associated overload management cost. Overload charge is then determined by distributing total cost due to overloading to overloaded trucks in terms of equivalent single axle load (ESAL).

Economic impact due to overloading is determined by conducting life time pavement performance and expected budget analysis. An efficient pavement management system with help of computer models allows prediction of future pavements performance, optimizing maintenance standards and prediction of total cost of road over design life.

## 2.2. Traffic in Flexible Pavement Design

According to Huang (2004), traffic load and environment are the most central factors that cause pavement deterioration. The relationship between traffic load and other variables on pavement performance was developed in AASHO road test undertaken in late 1950s (W. Schwartz & L. Carvalho, 2007). The AASHTO (1993) design equation, which is primarily based on the AASHO road test, gives a regression relationship between the number of load cycles, pavement structural capacity and performance, measured in terms of serviceability (W. Schwartz & L. Carvalho, 2007).

While it is true that a single maximum load could cause a failure, this load has to be very large. Pavements generally fail due to repeated application of axle load called fatigue failure. A summation of the equivalent effects of all axle loads during the design life of pavement results in an equivalent single-axle load (ESAL), which is the single traffic parameter for design purposes (Huang, 2004). The cumulative number of ESAL over pavement design period is predicted using the following equation.

$$ESAL = AADT * T * T_f * G * D * L * 365 * Y \dots \dots \dots 2.1 \text{ (Huang, 2004)}$$

Where

ESAL: Equivalent Standard Axle Load

AADT: Annual Average Daily Traffic

T: Percentage of trucks

T<sub>f</sub>: Truck factor

G: Growth factor

D: Directional factor

Y: Design period in years

Details of all variables of Equation 2.1 are discussed in Huang (2004). Truck factor is given more emphasis in this literature review. The truck factor (*T<sub>f</sub>*) in equation 2.1 is expressed as:

$$T_f = \sum(pi * LEFi) * A \dots \dots \dots 2.2 \text{ (Huang, 2004)}$$

Where

pi: Percentage of repetitions for i<sup>th</sup> load group

LEFi: Load Equivalence Factor for the i<sup>th</sup> load group

A: average number of axles per truck

There are three different procedures for considering vehicular load and traffic effects in pavement design: fixed traffic, fixed vehicle, and variable traffic & vehicle. As stated by Huang (2004), the great varieties of axle loads and traffic volumes and their intractable effects on pavement performance require that most of the design methods in use today be based on the fixed-vehicle concept.

In the fixed vehicle procedure, the thickness of pavement is governed by the number of repetitions of a standard vehicle or axle load. Load equivalence factor is used to account for the damaging power of a vehicle axle (Single, Tandem, Tridem) relative to some standard axle load, usually of 8,200 kg (18,000 lb) (Huang, 2004). The 18-kip single axle load was selected because it was the maximum legal load permitted in many states of the United States of America (USA) at the time of the AASHO Road Test (W. Schwartz & L. Carvalho, 2007).

### 2.3. Load Equivalence Factor

The first step in calculating ESALs for mixed traffic is to establish the load equivalent factor (LEF) of every axle of the traffic distribution. In AASHTO (1993), load equivalency factors were developed based on empirical data obtained from the AASHO Road Test. The AASHTO LEFs consider the four main variables, Axle load, Axle configuration, Structural number (for flexible pavements) and Terminal serviceability (W. Schwartz & L. Carvalho, 2007). Detail of regression equation developed based on results of the AASHTO road test could be found in Huang (2004).

In the mechanistic method of design, the LEF can be determined from the failure criteria. Deacon (1969) developed the LEF based on theoretical analysis of fatigue cracking failure criteria by a layered theory assumed value of  $f_2 = 4$  (Huang, 2004). Tensile strain at the bottom of asphalt layer was used as criteria. The general form equation is

$$LEF = \frac{W_{t18}}{W_{tx}} = \left(\frac{L_x}{L_s}\right)^4 \dots\dots\dots 2.3 \text{ (Huang, 2004)}$$

Where

$L_x$ : load in kip on a single axle / tandem/ tridem axle; and

$L_s$ : load in kip on standard axles which have the same number of axles as  $L_x$ .

If the equivalent axle load factor for one set of tandem or tridem axles is known then, it can be determined for other axles using Equation 2.3. The formula is known as Fourth Power Law which postulates an exponential relationship between axle loads and damaging power (Michael Ian Pinard, 2010). The general form of the equation is

$$LEF = \left(\frac{P_i}{P_s}\right)^n \dots\dots\dots 2.4 \text{ (Michael Ian Pinard, 2010)}$$

Where

$P_i$ : axle load,  $P_s$ : standard axle (usually 8.2 tones),  $n$ : power law exponent

Different power exponents could lead to difference in estimation of axle load impact on road damage. Different countries use different reference axle load and different power exponent factors. In Ethiopia, the damaging power of axles to a standard axle of 8.16 metric tons (80KN) and the damaging exponent factor  $n$  is 4.5 (ERA, 2002). According to Chinese specification, the standard axle for pavement design is 100KN (BZZ-100) with power factor of 4.35 (CCCC, *As built pavement report*, 2014).

The fourth power rule has also an important role in road damage and cost estimation, which includes toll charge, annual budget for maintenance and user cost design (Chan, 2008). Chan (2008) considered a damage exponent  $n=4$  value to calculate total ESAL for a case study in Anhui province China. The study considered the value as most reasonable through field studies of pavement performance and literature review.

Johnson (2004) also examined the Fourth Power Rule in a computable general equilibrium model of Sweden. The scope of the study was the effect of road wear and deformation of alternative to the fourth power rule. The results of study showed that computation with higher exponent (higher than four) resulted in increase of tax revenue and would help to decrease road wear (Johnson, 2004).

The use of power coefficient  $n=4.5$  has been practiced in Ethiopia for years. However, the factor was not developed under a range of loads and climatic and soils conditions representative of those prevailing in Ethiopia (ERA, 2002). ERA Pavement Design Manual I (2002) recommends caution to be applied in assessing the results of its use and sensitivity analyses are also recommended in final design.

In this study power coefficient recommended by ERA was directly utilized. However, the validity of power exponent ( $n=4.5$ ) needs to be verified through highway performance feedback system and further studies.

## 2.4. Axle Load Limits

### 2.4.1. Effect of Truck Size and Weight on Different Road Infrastructures

Truck size and weight have significant impact on important design parameters of highway infrastructure. Because trucks are the biggest and heaviest users of highway and bridge infrastructure, the size and weight limits set for them define the necessary strengths of pavements and bridges, lane widths, horizontal and vertical alignments that designers and engineers accommodate in building infrastructure (New Brunswick Department of Transportation, 2010). Table 2.1 demonstrates Highway infrastructures affected by truck size and weight which was developed by. Considering these factors most countries have a standard for allowable axle load limit and vehicle dimension.

The axle weight (loading) and gross vehicle weight (GVW) are two aspects of truck weight that are interdependent and that interact with the highway infrastructure. As shown in Table 2.1, the effect of axle weight is more significant to pavements and short-span bridges, whereas GVW is of more significance to long-span bridges (New Brunswick Department of Transportation, 2010, The U.S. Department of Transportation, 2000).

Table 2.1 Highway Infrastructure Elements Affected by Truck Size and Weight Limits

Highway Infrastructure Element		Axle Weight	GVW	Axle Spacing	Truck Length	Truck Width	Truck Height
Pavement	Flexible	E		E			
	Rigid	E		E			
Bridge Features	Short-Span	E		E	E		
	Long-Span		E	E	E		
	Clearance					E	E
Roadway Geometric Features	Interchange Ramps		E		E	E	
	Intersections				E	E	
	Climbing Lanes	E					
	Horizontal Curvature		E		e		
	Vertical curve length		E				
	Intersection Clearance time		E		E		
	Passing sight Distance				e		

Key: E=significant Effect e= Some Effect

As described above, overloading has several impacts. However, the literature review and the focus of this study were on impact of overloaded trucks on flexible pavements in Ethiopia.

## 2.4.2. Axle Load Limits

In flexible pavements, the effect of the exponential relationship between axle load and its damaging effect is that most road wear is caused by vehicles with more heavily laden axles (Michael Ian Pinard, 2010). While damage to the road network by heavy vehicles cannot be eliminated, it is clearly in the interest of the travelling public and the road hauler that all reasonable steps be taken to minimize the deterioration of roads and streets (Department of Transport Directorate, 1997)

The axle load limits are meant to ensure that roads last for their full design life with normal maintenance expenditures. In addition, control of axle loads to prescribed limits can be justified for the following reasons (Africon Ltd, 2011);

- Limiting the extent of road maintenance required;
- Reducing the amount of fuel levy required;
- Improving road safety and ensuring a level playing field between transport service providers.

Consequently, axle load limits are set to protect the road asset and to maintain a reasonable balance between road construction as well as road maintenance costs on the one hand, and the economy of the road industry as a whole on the other (Department of Transport Directorate, 1997). A similar principle was forwarded by Michael Ian Pinard (2010) as demonstrated in Figure 2.1.

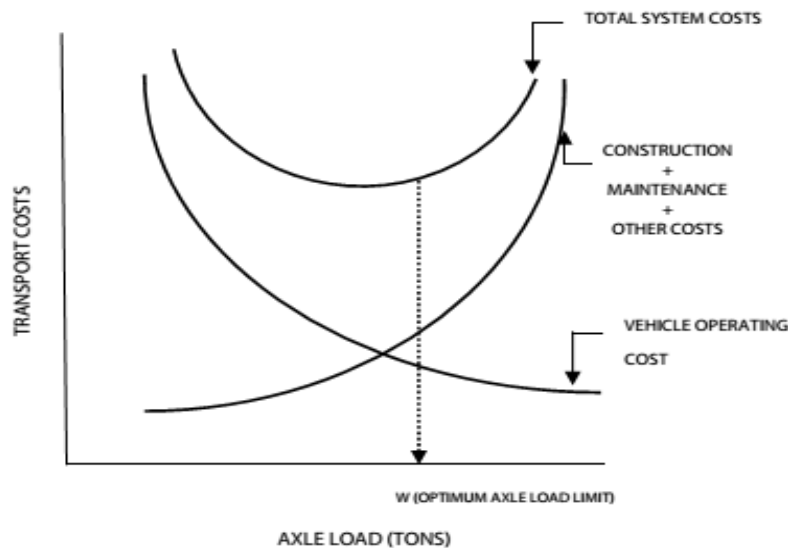


Figure 2.1 The Concept of Economic Axle Load Limit (Michael Ian Pinard, 2010)

Thus, balance of the road transport system would not be achieved if either heavier axle loads were to cause more damage to the road infrastructure than benefits accruing from a reduction in freight transport costs or, conversely, if lighter axle loads were to cause more loss of freight transport benefits than savings in infrastructure costs (Michael Ian Pinard, 2010).

On the basis of an Axle Load Study for Southern Africa carried out by the Southern African Transport and Communications Commission (SATCC) in 1999, optimum axle load and maximum vehicle mass limits were determined using Highway Design and Maintenance (HDM-III) model. The regional optimum single axle load limit was determined as 13 tons considering and minimizing the total transport cost on a regional basis for the regional economy (Michael Ian Pinard, 2010).

However, based on consideration of the axle load Economic Efficiency Frontier, in terms of the benefits versus costs of increasing from the prevailing limits to the optimum limit, the harmonized limits recommended for the region were less than the optimum limits. The large proportion of sub-standard pavements, a significant amount of backlog maintenance and concern over the adequacy of future maintenance funding were additional reasons for recommending lower limits than optimum limit (Michael Ian Pinard, 2010).

### 2.4.3. Harmonization of Axle Load Limits

The vehicle load limits in Eastern and Southern Africa can generally be said to have evolved over the years on no particular basis other than what might be described loosely as “historical trends” (Michael Ian Pinard, 2010). A legal axle load limit in one country could be illegal in others. The lack of harmonization creates intra-regional trade and logistic barriers among countries. Various regional economic communities in Africa have tried to harmonize axle load limits in different countries. Table 2.2 presents comparison axle load limits recommended by regional communities in Eastern and Southern Africa (Michael Ian Pinard, 2010).

Table 2.2 Comparison of Regional Economic Communities’ Vehicle Load Limits

Regional Economic Community	Axle load Limits (tons)				Per. Max Comb. Mass (tons)
	Steering Axle (2 tyres)	Single Axle (4 tyres)	Tandem axle (8 tyres)	Tridem axle (12 tyres)	
COMESA	8.0	10	16	24	53*
SADC	8.0	10	18	24	56
ECOWAS	8.0	12	21	25	51
CEMAC	8.0	13	21	27	50

\* Permissible maximum combination mass

There exist differences in axle load limits of different regional economic communities in eastern and southern Africa as indicated in Table 2.2. Although the difference may look small, the damaging effect could be considerable due to exponential relationship between axle load and its damaging power. Harmonizing axle load limits, vehicle dimensions and GVW limits is therefore vital for integrated and efficient road transport and intra regional trade among African Countries (Michael Ian Pinard, 2010).

## 2.5. Impact of Overloading

### 2.5.1. Introduction

Overloaded trucks traffic is a serious problem in many developing countries because it incurs huge cost in terms of maintenance and rehabilitation of road network (Chan, 2008). Based on the Africon (2011) Report, 15% - 20 % of heavy vehicles in Southern Africa were overloaded and had caused 57% of the damage to the roads as illustrated in Figure 2.2. This implies that a significant portion of the damage of the road was caused by overloaded vehicles.

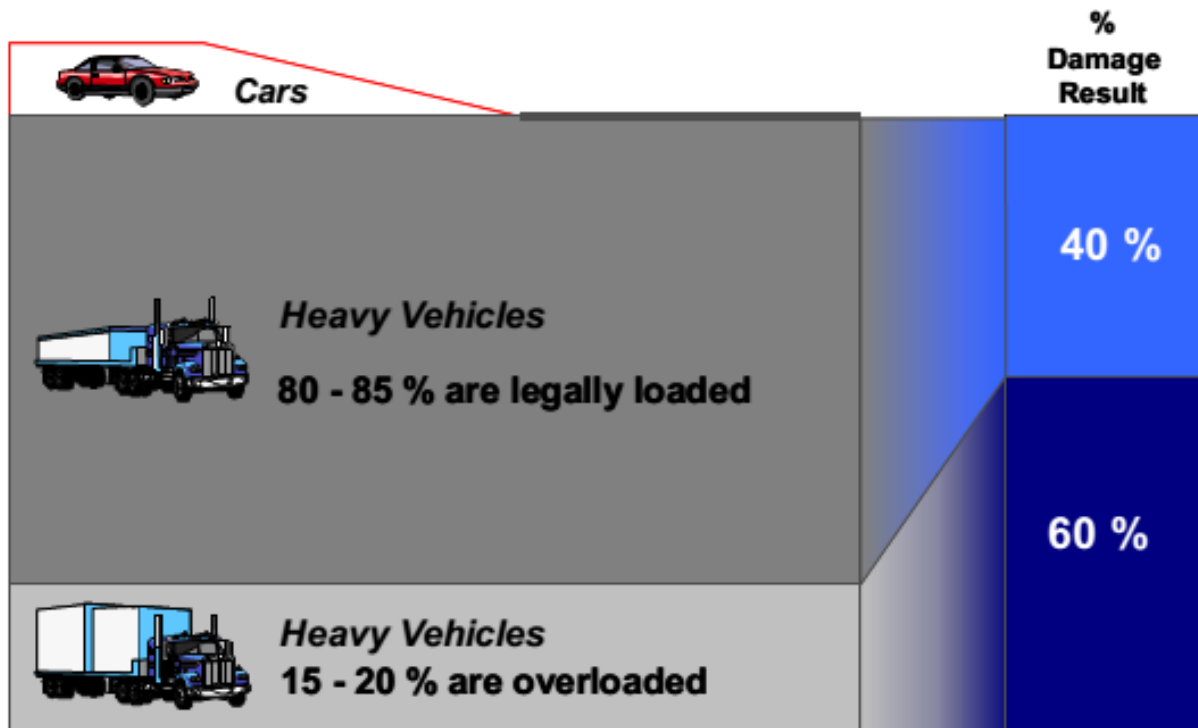


Figure 2.2 Contributions to Pavement Damage by Vehicle Category (Department of Transport Directorate, 1997)

Overloaded vehicles also increase severity of a traffic hazard, especially regarding the heavy vehicle's braking system and additional braking distance involved. On steep uphill gradients where no climbing lane is provided, the slow moving heavy vehicle causes traffic disruption.

### 2.5.2. Economic Impact of Overloading

The marginal cost associated with an overloaded vehicle on a road comprises three main components. The first one is increase in vehicle operating costs to other vehicles (Africon Ltd, 2011). This increase in Vehicle Operating costs reflect road deterioration resulting in increased vehicle operating costs and lower speeds, ensuing in higher time costs. It should be noted that vehicle operating costs and transport costs are not the same. Transport costs incorporate VOCs, environment, accident, etc. while vehicle operating costs are costs incurred by vehicle owners excluding external costs. Secondly, assuming that routine maintenance actions are condition responsive, overloaded vehicles on a road would lead to earlier and more frequent maintenance interventions. The third cost is reduced pavement life. Overloading will lead to the road authority remedying the damage by way of reconstruction/rehabilitation at an earlier date than would have not been the case without the additional load.

When both time and cost factors are combined, overloading result in increased costs to road agencies. When this adverse impact is extrapolated to a large proportion of a country’s road network, roads agencies' costs are unnecessarily high (Michael Ian Pinard, 2010). As result of overloading, the actual service life of the pavement is reduced. This in turn results in major reconstruction/rehabilitation work to be carried out sooner than the intended design life. The thickness of overlay required for rehabilitation is also increased as it is shown in figure 2.3(Michael Ian Pinard, 2010).

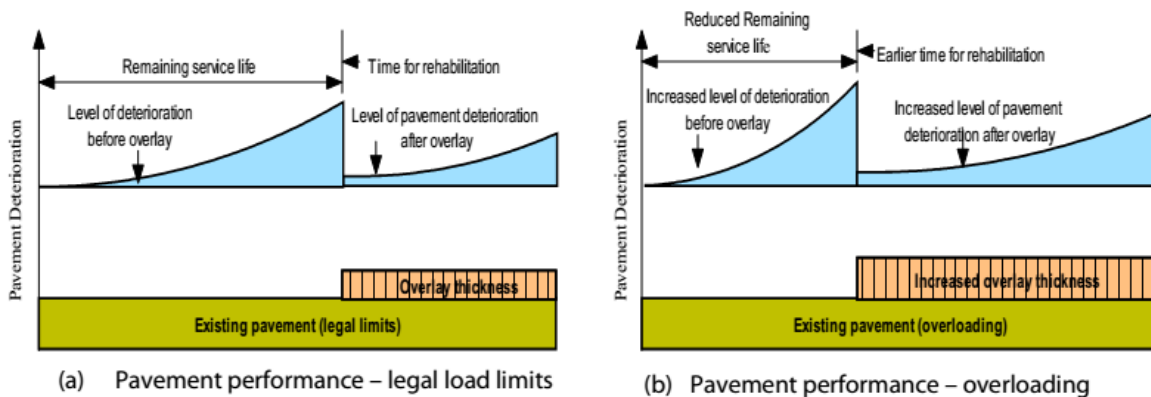


Figure 2.3 Pavement Performances With and Without Overloading

Traffic accidents caused directly or indirectly by overloaded heavy vehicles are normally not included when the total overloading cost to the country is calculated (Department of Transport Directorate, 1997). A similar conclusion on economic impacts of overloading was made by Chan (2008). His study classified economical losses to road agency due to overloading as; reduction of pavement life, increase of maintenance cost and increase of rehabilitation cost. Additional cost of overload management was also included. As a result, net present value (NPV) of pavement investment with overloading truck traffic was higher than design traffic (Chan, 2008).

### 2.5.3. Reduction of Pavement Life

The impact of overloading on a pavement is to accelerate its deterioration and to cause the pavement to reach its terminal level, usually as a result of unacceptably high levels of rutting or roughness, much sooner than would have been without overloading (Michael Ian Pinard, 2010). The reduction in pavement life is as illustrated in Figure 2.3. Table 2.3 illustrates the effect of axle load on the design life of a pavement loaded above an assumed legal limit of 10 tons for varying power exponents.

Table 2.3 Effect of Axle Loads on Pavement Life (Michael Ian Pinard, 2010)

Design Axle load limit (tons)	Actual Axle load (tons)	Equivalence factor			Pavement life in years		
		n=4	n=4.5	n=5	n=4	n=4.5	n=5
10	10	1.0	1.0	1.0	20.0	20.0	20.0
10	11	1.5	1.5	1.6	13.7	12.9	12.4
10	12	2.1	2.3	2.5	9.7	8.8	8.0
10	13	2.9	3.3	3.7	7.0	6.1	5.4
10	15	5.1	6.2	7.6	3.9	3.2	2.6

As example, a single axle that is overloaded by just 20 per cent over an assumed legal limit of 10 tons, i.e. loaded to 12 tons, with an assumed power exponent of 4.0, has damaging effect over twice of the legally loaded vehicle (equivalence factor = 2.1). Moreover, if the pavement were continually subjected to such overloading, its life would be reduced from 20 years to less than 10 years (Michael Ian Pinard, 2010). However, actual traffic is not constant through design life of pavement.

Chan (2008) in his study of truck overloading in developing countries and strategies to minimize impacts, considered six road sections in Anhui Province, China. Road sections were selected based on economic role connecting freight traffic. The study performed actual traffic and axle load survey to determine overload pattern. In the study, statistical analysis of traffic data was primarily performed to determine the distribution AADT and overloading on each truck group and road sections. The mean ESAL without and with overloaded trucks was then determined.

The study considered pavement damage exponent  $n=4$  as most reasonable value to calculate total ESAL. Consequently the actual life of a pavement was found to be 11.24 years with 26% reduction from its initial design period of 20 years.

#### **2.5.4. Increase in Maintenance and Rehabilitation Cost**

Chan (2008) also made assessment was on future annual periodic maintenance required with overloaded and normal traffic. A road section, G206, in Anhui Province, China was considered to analyze economic loss due to overloaded trucks. The study primarily considered maintenance and rehabilitation cost. In this study additional cost of overload management was also included. However, increase in vehicle operating cost associated with increase in roughness of the road due to overloaded trucks was not included.

Chuan (2008), also adopted maintenance strategies used by Anhui province. The NPV without overloaded truck traffic was then determined based on design pavement life (20 years). The NPV of investment for pavement with overloaded truck traffic was found based on actual pavement life (11.24 years). Based on findings of the study, overloaded truck of the study road section showed a 105% increase in maintenance expenditure.

Chuan (2008) did not discuss maintenance strategy (maintenance types and intervention criteria) used for the study and their justification. This limits justification and transferability of NPV results for overload fine analysis. Unfortunately, there are no optimized maintenance standards by road classes in Ethiopia

The Chuan (2008) study also made final comparison between increase in NPV and reduction in pavement service life separately. However, the two factors (reduction in pavement life and increase in maintenance cost) were not combined into a single economic cost. Computing rationalized overload fine requires determining total economic loss due to overloading through lifecycle cost analysis.

## 2.6. Reasons for Overloading

### 2.6.1. Economic justification of Overloading

Once axle load limits are set, every road user is expected to respect enforcement. Fixed Weighing Stations are available for this purpose. However, heavy freight transport vehicles usually violate the allowable load limit. Overloading is an honest mistake for some first time drivers who lack awareness. On the contrary most overloaded vehicle operators exactly know what they are doing (Africon Ltd, 2011).

Strathman (2001) in his research note described the economic rationale for exceeding weight limits by vehicle operators in the face of weight enforcement activities. The study proposes that vehicle operators are encouraged to load to the level that will yield maximum profit to freight transporters. In principle, this implies that transporters exceed legal weight limits to the point where additional revenues obtained from overloading are just offset by additional costs. This assumption supports the view that vehicle operators are reluctant to self regulate because they take decision of vehicle loads purely on net revenue or other commercial criteria, without consideration to the pavement damage costs (EGIS, 2010).

The benefits of overloading were defined as the revenue from loading compared to the costs, including the vehicle operating cost and expected penalty from detection through weight enforcement activity (Strathman, 2001). Focusing on operating revenues and costs, the study represented the net operating profit per mile to the overloading carrier using relationship shown in Equation 2.5:

$$\pi = r * (W_{limit} + W_{excess}) - P_d * f(W_{excess}) - c * (W_{limit} + W_{excess}) \dots 2.5 \text{ (Strathman, 2001)}$$

Where

$\pi$ : Net operating profit per mile

r: Revenue per ton –mile;

$W_{limit}$ : Legal load limit, in tons;

$W_{excess}$ : Load in excess of legal limit, in tons;

$P_d$ : Probability per mile of detection by weight enforcement activity;

$f(W_{excess})$ : Penalty associated with overloading, which is defined to be a function of the level of overloading;

c: Operation costs per ton-mile

The study defined both the revenue and cost components of Equation 2.5 to be linear for simplicity. First order conditions for maximizing operating profits per mile from overloading were obtained by differentiating Equation 2.5 with respect to excess load, or:

$$\frac{\partial \pi}{\partial W_{excess}} = r - P_d f'(W_{excess}) - c = 0 \text{ or} \dots\dots\dots 2.6 \text{ (Strathman, 2001)}$$

$$r = P_d f'(W_{excess}) + c \dots\dots\dots 2.7 \text{ (Strathman, 2001)}$$

$$\text{Where } f'(W_{excess}) = \frac{\partial f(W_{excess})}{\partial (W_{excess})}$$

From Equation 2.7, the operating profits per ton-mile were maximized when the marginal revenue from overloading is equal to the marginal additional operating costs plus the marginal expected penalty from detection through weight enforcement. As can be seen, the expected penalty is comprised of two elements. The first,  $P_d$ , is an indicator of the intensity of weight enforcement activity, while the second,  $f'(W_{excess})$ , reflects the severity of the marginal fine imposed on a detected over loader.

Accordingly, the study recommends, two possibilities through which highway officials can seek to reduce overloading activity through increased enforcement, stiffer penalties, or both.

## 2.6.2. Week Overload Management

Chuan (2008) in his literature review on "Study of Truck Overloading in Developing Countries and Strategies to Minimize Impacts", described overloading as a common phenomenon in both developing and developed countries. However the problem is more serious in developing countries due to weak highway management system. The study suggested that, in developing countries, economic growth is faster than the road management system and is a reason towards overloading. Weak road management system includes unclear legislation, weak enforcement, etc.

Chuan (2008) Suggest that unclear legislation system, incompatible laws, and lack of similar attitudes towards overloading create a loophole for rule breakers.

Fixed weighing stations alone were not effective in overload management. This is because fixed weighing station operations are quickly communicated and easily evaded by motor carriers, either by pulling off the road or by diverting to alternate routes (Strathman, 2001).

Weak overload management can also be explained in terms of fines imposed on overloaded trucks. The fine imposed for overloading, both by traffic officers for admission of guilt and by magistrates in a court of law, in most cases, is unrealistically low compared with the damage done by the vehicle on the road and the higher profit made by the hauler in transporting a heavier load (Michael Ian Pinard, 2010).

Overload fines also lack consistency if they are imposed considering factors that have no direct relation with amount of damage caused to the pavement. If trucks overloaded to the same amount are not fined equally, transport enterprises will offer different price to clients. This creates unequal competition among transporters that in turn encourages more overloading.

Inconsistency can also be expressed in terms of working hours of weighing stations. Fixed weighing stations are open during the day and decrease their hours at night due to a shortage of staff power supply etc (Michael Ian Pinard, 2010) . This creates additional loophole for rule breakers, and thus led to unfair competition among truck drivers since violators with overloaded cargo can offer cheaper transport costs to customers in proportion to the excessive loads they carry.

## 2.7. Proposed Solutions to Prevent Overloading

### 2.7.1. Policy Alternatives for Governments to Deal with Overloading

Chuan (2008) presented three alternative suggestions by for governments to deal with overloading as follows

- **Do-Nothing:** The governments do nothing to maintenance quo. This approach would cause heavy burden to the government as economic loss due to poor road condition that would be unfair for tax payers who use the road appropriately. . If overloading is not controlled, repair and reconstruction is an avoidable outcome to roads Authorities. Hence this suggestion of doing nothing was not accepted.
- **Maintain roads to desired standard combined with strict law enforcement:** This approach is applied in most countries as it is the most effective method to eliminate overloading. Existing measures shall be adjusted to a suitable level. Fair computation among truck operators and other modes would be encouraged.
- **Upgrade highway system to carry higher axle load limits:** This approach involves long term projects that would involve several significant factors; which include technical feasibility, transport economic feasibility, road safety, fair trade etc. This approach would require higher investment, which would be unfair to the majority of tax Payers who are not overloading. This approach also requires capital investment to upgrade roads for overloading. However upgrading highways for higher axle load limit wouldn't stop overloading:- this is because transporters would try to provide cheaper transport rate to customers and make more profit through overloading regardless of axle load limit. This situation could be illustrated through case study in South Africa. Between 1977 and 1996 the gross combination mass was increased from 38tons to 56 tons, and the payload increased from 24tons to 25 tons. However incidence of overloading in the same period has increased regardless of increase in weight limits (Chuan 2008).

The most appropriate situation depends on specific case of a country. Chuan (2008) recommends Alternative 2, which involves a balance between legal enforcement and maintaining highway to desired standard as the most suitable solution to reduce overloading and provide good condition roads to the road users.

The current practice in ERA also resembles alternative 2. As the Addis Ababa – Djibouti road corridor is the main gateway from Djibouti Port, maintenance works are performed considering road condition. Overloading enforcement is also performed at fixed a Weighing station that is at Awash and Modjo weighing stations.

### 2.7.2. Solutions to Prevent Overloading

Chuan (2008) recommends combining; monitoring, legislation and education to control overloading. **Monitoring** involves strict enforcement accompanied with intense enforcement to control drivers diverting routes with help of efficient highway monitoring system. The study recommends a 24 hour all weather monitoring system. **Legislation** includes defining similar attitude towards overloading and defining compatible laws. Although the impact is long term, **Education** was also recommended as a strategic means of overload control as educated truck operators are less likely to overload.

Chuan (2008), in his literature review, also proposed for modification of standards and the use of technology in overload reduction. The first approach includes increasing the gross vehicle weight without extra pavement damage. Higher gross vehicle weight limits could be introduced to the highway system through vehicles fitted with road friendly suspension system. This approach benefits governments by saving maintenance and rehabilitation costs. It also benefits truck operators by providing higher gross vehicle mass. This procedure was recommended for developing countries to reduce pressure on freight demand.

Chuan (2008) also defined three levels that pavement damage could be reduced through increasing area of axle load. First, for constant gross vehicle weight, trucks with more axles cause less damage than trucks with fewer axles. Second, for trucks with the same axle group, dual tire cause less damage than single tire and third, wide base tires also cause less pavement damage.

Load sensors and Axle load calculators are also available to transporters to avoid overloading. There are several axle load calculators (software) that provide fair approximation of axle weight based on vehicle type, spacing of axles, load amount and loading geometry.

### 2.7.3. Impact of Enforcement Vs Penalty in Overload Reduction

Strathman (2001) proposes that state highway officials can seek to reduce overloading activity through increased enforcement, stiffer penalties, or both. The study performed statistical analysis based on weight enforcement data of forty-eight States of the USA. The forty-eight States were grouped to four cases that combine different intensities of enforcement and relative penalties. These include states that combine:

- I. Relatively small penalties with relatively extensive enforcement;
- II. Relatively low levels of enforcement with relatively high penalties;
- III. Relatively high penalties with relatively intensive enforcement; and
- IV. Relatively small penalties with relatively low levels of enforcement.

Considering the above enforcement strategies and conceptual framework, regression model was developed to study which case is more effective in deterring overloading. Two models were developed based on alternative treatment of the number of vehicles weighed. Model 1 specifies the total number of weighing while Model 2 distinguishes between weighing on fixed locations and portable/semi-portable scales.

The results of Strathman (2001) Study indicate that the relative consequences of enforcement intensity or overweight penalties are about the same in terms of preventing overloading activity. The enforcement intensity effect was found to be largely associated with the use of portable/semi-portable scales, which accounted for less than two percent of total vehicle weight. Strathman (2001) concluded that *States to either increase fines or intensify enforcement to prevent overloading, with the former likely being more cost-effective given the findings of this note*”.

The result of the study was also consistent with other previous studies on enforcement deployment strategies. Weighing at fixed locations is much less effective than at variable locations with portable scales (Strathman, 2001). This is because fixed weigh station operations are quickly communicated and easily evaded by motor carriers, either by pulling off the road or by diverting to alternate routes (Strathman, 2001).

Michael Ian Pinard (2010) argues that fines do not have a significant effect on discouraging overloading as fines imposed both by traffic officers for admission of guilt and by magistrates in a court of law remain, in most cases, unrealistically low compared with the damage done by the vehicle on the road and the higher profit made by the hauler in transporting a heavier load.

In general, intensive administrative approach of overload management along with overload fee that commensurate actual damage due to overloading are considered best strategies of preventing overloading.

## 2.8. Overload Fine Analysis

### 2.8.1. Introduction

Fee Schedules for Overloading were prepared by SATCC in 1993 with various assumptions for calculating the fee schedule which was based on the 1993 Southern Africa Development Community (SADC) Axle Load Study for Southern Africa (Michael Ian Pinard, 2010).

The underlying rationale within the proposed fee structure was that the fees levied will clearly outweigh any benefits to the operator from overloading for commercial gain (Michael Ian Pinard, 2010). The SATCC fee schedule for overloading has provided the basis for charging overloaded trucks in a number of countries in the Eastern and Southern Africa region. The report however didn't describe detail factors and procedure involved in overload fine analysis.

Once the fee schedule is prepared, overloaded vehicles within weighing limits would pay specified fee at the weighing stations. This procedure simplifies transporters' lives and also provides an option to axle load harmonization. This method also creates the opportunity for the private sector to take part in axle load management stations. However, fee schedules need to be regularly updated based on updated information within the road network considered (Michael Ian Pinard, 2010).

As literatures reveal, determination of rational overload fine requires understanding the economic loss due to overloading. The economic loss, reduction in pavement life, increase in vehicle operating cost and other costs associated with overloaded trucks are discussed under Section 2.5.

Prediction of pavement damage and other costs is therefore required prior to determining overload fine that commensurate actual pavement damage due to overloading. Literatures recommend for establishment of pavement management system that assist in determining optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time. Computer models also assist in prediction of future pavement condition and amount of road works involved in lifecycle analysis. In this study a road deterioration model of HDM-4 is reviewed based on literatures and HDM-4 manuals.

### 2.8.2. Overload Charge

Abdissa (2008), in his study on commercialization of roads in Ethiopia, a case study on Addis Ababa - Adama Road, defined "road user charge" as a fee for use or a charge levied to cover the cost imposed by vehicle use on the rest of society. Charges include taxes, fees on vehicles, parts, fuels and tolls (Abdissa, 2008).

Most road user charges are applied in terms of taxes. However, where a specific road fund has been set up then the charges are not considered as part of taxation. A road toll for using specific facility will also not be considered as tax (Abdissa, 2008). Similarly overload charges cannot be applied as tax because the fine is applied only to overloaded trucks. The following items are considered in overload charge analysis as discussed in previous sections.

- **Economic Loss due to overloaded trucks;** costs related with increase in maintenance and rehabilitation cost, related vehicle operating cost and travel time etc.
- **Overload Management Cost;** costs related to weighing stations operation and management.

Budget estimates are performed considering cases with and without overloading. The difference in optimized budget estimates will serve as a base of estimating overload fines. For Bitumen paved roads equivalent standard axle load (ESAL) is used as a sole base for allocating variable costs (Abdissa, 2008). Accordingly overload charge can be assigned to overload trucks based on their contribution to extra cost due to overloading.

The overload charge collected would then serve as collected revenue for road fund and a means to manage and maintain the standard of the road to the desired level of service.

## 2.9. Pavement Management System

Effective and timely maintenance of roads and bridges under budgetary restriction is necessary to keep the network in good condition. This requires an efficient Pavement Management System (PMS) in Road and Highway Departments (Kahn, 2005). PMS have been defined as a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time (AASHTO, 1993). They also provide the information needed to support fund requests and justify maintenance and rehabilitation programs (Huang, 2004).

This overall PMS is generally composed of two major sub-systems: information management system and decision support system. The information management system is the collection, storage and management of the required data; whereas, the decisions support system is the collection of algorithms that analyzes the data and provides recommendation to managers (Huang, 2004).

Pavement management can be divided into two generalized levels: project and network. At the project level, consideration is given to alternative design, construction, maintenance, or rehabilitation activities for a particular project within the overall program (The U.S. Department of Transportation, 2000). The basic elements of a network-level PMS include an inventory, a condition assessment, determination of needs, prioritization of projects needing maintenance and rehabilitation, a method to determine the impact of funding decisions, and a feedback process (Huang, 2004).

In both cases, the elements in analysis include: details about network; condition of network at start year; different distress and maintenance strategies; analyze and predict future need of network; optimize strategies and budgets; and implementing a feedback system to: update costs and life expectancies, revise strategies, and improve reliability of the system. Detail, network-level and project level elements are discussed in Appendix E of Huang (2004).

Computer software, a pavement management system (PMS) can be developed to assist decision makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a given period of time (Huang, 2004).

In this study procedure of optimizing strategies and predicting lifecycle budget requirements using HDM-4, which is currently in use by ERA, is selected for review and the Road Deterioration Sub-Model is considered for data analysis.

## 2.10. HDM-4 Model

### 2.10.1. Introduction

An international effort to develop improved road investment appraisal methods was undertaken by the British Overseas Development Administration, the Asian Development Bank, the Swedish National Road Administration, the Inter-American Federation of Cement Manufacturers and the World Bank. This study was built upon the widely-used Highway Design and Maintenance Standards model HDM-III.

Emphasis in the study was on collating and applying existing knowledge, rather than undertaking major new empirical studies. However, the end product of the study was a completely new software package and associated documentation which will serve as the primary tool for the analysis, planning, management and appraisal of road maintenance, improvements and investment decisions that will supersede HDM-III (1995 HDM System).

The latter version, the Highway Development and Management model, HDM-4 assists managers to predict the future economic, technical, social and environmental outcome of possible investment decisions concerning maintenance management of pavements. Four different sub models are incorporated in HDM-4, namely, Road Deterioration sub- model (RD), Road Works Effects sub-model (RWE), Road User Effects sub-model (RUE) and Social and Environmental Effects sub-model (SEE).

Effective road decision model should have pavement deterioration modeling capability which predicts the future condition and the effects of maintenance on the pavement. The Road Works Sub-model of HDM-4 is used to predict:

- Timing of works over the analysis period;
- Calculation of the physical quantities or amounts of works to be undertaken;
- Estimating the costs of works; and
- Resetting / changing one or more of the characteristics that define the road.

### 2.10.2. Road Deterioration Sub-model

The Road User Effects Sub-model (RUE) allows calculating annual Road Agency and Road User costs.

The Road Deterioration Sub-model uses the Structural mechanistic-empirical approach. This is identifying the functional form and primary variables and then applying various statistical techniques to quantify their impacts using empirical data. Pavement strength, age and condition for initial analysis year are used as input in predicting the road deterioration. Traffic loading is calculated. Surface distress and increase in roughness are then predicted using internal models. The effect of any condition responsive or scheduled maintenance works assigned will be analyzed. This allows predicting the post-maintenance condition, age strength, age of the pavement, and in turn serves as an input for next cycle.

### 2.10.3. Distress in Flexile Pavement

It is necessary to have clear understanding of the type of pavement distress, prior to evaluation and treatment selection. Pavement defects can be classified as structural and functional. Structural failure is associated with the ability of the pavement to carry the design load; whereas, functional failure is associated with ride quality and safety (Huang, 2004). When structural failure increases in severity, it always results in functional failure as well. The non-load-associated distress is caused by climates, materials, or construction. A non-load-associated distress might be increased in severity by traffic loads (Huang, 2004).

Most failures in flexible pavements include alligator (fatigue) cracking, block cracking, lane or shoulder drop-off, longitudinal and transverse cracking, raveling, pothole, rutting, swell, bleeding etc. Pavement distresses could be the result of environment (climate), drainage (moisture) and material, load or combination of factors (Alebachew, 2005).

Flexible pavement distresses modeled in HDM-4 include: pavement surface distress, deformation distress, pavement surface texture distress and drainage distress. The effect of construction quality is also included. Surfacing Distress modeled in HDM-4 includes: cracking (structural & thermal), raveling, potholing and edge break. For each type of distress, separate relationships are given for predicting the time to initiation and the rate of progression.

Deformation Distress modeled in HDM-4 include: rutting and roughness (IRI). HDM-4 rut depth model is based on four components. These are: Initial Densification (RDO), Structural Deformation (RDST), Plastic Deformation (RDPD), and Wear from Studded Tyres (RDW) Roughness is defined as deviations of surface from true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads and drainage, expressed in the International Roughness Index, IRI (m/km). HDM-4 also provides model for prediction of road roughness.

Pavement Surface Texture Distress modeled in HDM-4 includes: texture depth and skid resistance. Detail of all distress types along with models considered in HDM-4 are discussed in HDM-4 road deterioration manual (Morosiuk et al, 2004).

#### 2.10.4. Treatment Types

Maintenance programs can be categorized into routine, periodic and extraordinary maintenance (rehabilitation). Road works are classified as preservation and development in HDM-4. HDM-4 preservation works include

- **Routine Maintenance:** This is required for pavement and non-pavement needs. In a pavement life cycle, routine maintenance are usually assigned each year and when necessary. Routine maintenance includes
  - Patching, Crack sealing, edge repair, spot re-graveling, shoulder repair etc
  - Drainage: culvert repairs, clearing side drains; and
  - Miscellaneous: Vegetation control, marking, signs etc
- **Periodic Maintenance:** Periodic maintenances are required based on road condition, traffic and roughness, or they may be scheduled. The following are types of periodic maintenance
  - Preventive treatments: fog seal, rejuvenation ;
  - Resurfacing: Surface dressing, slurry seal, cape seal, re-graveling
  - Rehabilitation: overlay, mill and replace, inlay; and
  - Pavement reconstruction: Partial or full pavement reconstruction
- **Special works include**
  - Emergencies: Clearing debris, repairing washout' subsidence, traffic accidents removal etc. Winter maintenance: snow removal, salting, gritting etc

#### Development works include

- **Improvements**
  - Widening: partial widening, lane addition
  - Realignment: horizontal and vertical geometric improvement, or junction improvement
  - Off-carriageway works: Shoulder addition, shoulder upgrading, NMT lane addition, side drains improvement etc
- **Construction work include**
  - upgrading by changing the surface class and
  - New sections: dualisation of existing link, new link

Detail of work standards involved in HDM-4 and their hierarchy is discussed in HDM-4 manuals. HDM-4 performs economic analysis based on alternatives specified by user. It is recommended to first identifying all possible type of road works in a country prior to determining optimum standards through strategy analysis (Archondo – Callao, 2008).

### 2.10.5. Maintenance Intervention Criteria

Generally, decision criteria (or commonly known as trigger values) for pavement maintenance and rehabilitation are normally based on condition, surface type, functional classification, and traffic loading (Huang, 2004). Engineering criteria for a pavement condition evaluation involves riding comfort (IRI), structural capacity (SN), safety (skid resistance) and measure of distress. Maintenance cost and user costs are also considered in economic analysis (Alebachew, 2005).

In general, this requires that the condition of the individual pavement sections, without maintenance or rehabilitation, be projected to a common period and into the future in terms of individual distress, PCI (Present Condition Index), PSI (Present Serviceability Index), or some combination index as illustrated in Figure 2.4.

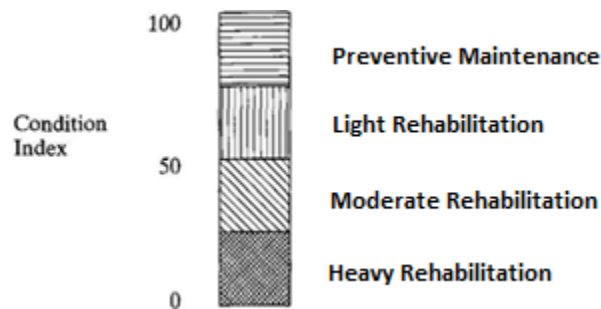


Figure 2.4 Trigger Value Example Ranges (Huang, 2004)

Many pavement managers use PCI to track pavement distress over time and apply maintenance treatments. Pavements are usually maintained and/or rehabilitated when the PCI drops to level of 40-60 (Alebachew, 2005).

Egis Bceom International (2010) in their study on Strategic Review of Ethiopian road sector development have used scheduled intervention as depicted below with objective to avoid large delays due to maintenance works, due to difficulty of maintenance works etc.

- Federal Asphalt Roads: 10 years periodicity;
- Federal Gravel Roads: 5 years periodicity,
- Regional roads: 3 years periodicity, and
- URRRA : 2 years periodicity

Routine maintenance: the whole network is considered to undergo routine maintenance annually. On the contrary, Abdisa (2011) in his study on Commercialization of Road in Ethiopia assigned periodic maintenance at 5 years periodicity. However both studies did not discuss economic justification of selected maintenance standards.

Maintenance interventions in HDM-4 could be scheduled at fixed time interval or be responsive to some trigger values. Scheduled intervention involves fixed time intervals between interventions. Responsive intervention is set depending on pavement condition, pavement strength, surface age, traffic volumes/loadings etc.

Pure scheduled intervention is not recommended as the interval between road works which should change over time to account traffic growth. Purely condition responsive alternative is also not recommended as the same type of work for the entire period may not be justified (Archondo – Callao, 2008). Road work per road class should be selected considering feasibility from technical point of view, yield reasonable design life and realistic results (Archondo – Callao, 2008).

Similarly, Khan (2005) considered roughness (International Roughness Index, IRI), road condition, and traffic volume and treatment intervals to determine trigger levels for each treatment at network level. Generally, when roughness reaches close to the standard, treatment is required to restrain road roughness (Khan & B.Odoki, 2005). An IRI value in the range 3-5 was applied in optimization for primary highways in Bangladesh.

In the study, Maintenance Standard was a set roughness for a road at its life cycle, which also represents the allowable limit for road deterioration. Final maintenance standard, among alternatives, was selected using HDM-4 Strategy analysis. Optimum maintenance standard was selected based on criteria of maximizing NPV/cost from HDM-4 outputs as discussed in the following sections.

### 2.10.6. Optimizing Maintenance Standard

In general, road authorities are primarily interested in a good performance of the road network at the lowest possible costs. Good performance especially implies functional performance of the road which includes safety, comfort, driving speed and limited delay due to lack of capacity or due to maintenance works (Molenaar, 2006). This requires an organized and balanced maintenance program to realize the maximum service during life of the road-network.

More than one maintenance strategies (treatment types and timing) may provide desired performance over analysis period. Hence, the best maintenance strategies that provide desired service at a least life-time cost should be identified (Khan & B.Odoki, 2005). Life-cycle cost analysis is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future cost, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project (Huang, 2004).

For planning purpose, each road authority should have complete sets of treatment intervention criteria for all treatments. If they are not available, maintenance standards should be developed using studies conducted on some selected road sections.

Khan (2005) developed optimum pavement maintenance standards using the HDM-4 model for 48 road groups in Bangladesh. In the study possible maintenance standards and treatments were identified. Standards and corresponding treatments were set using “Routine Maintenance + Periodic Maintenance Treatment at a fixed IRI” approach. Maintenance standards-treatments matrix was then created for primary road group as shown in table 2.4 (Khan, 2005).

Table 2.4 Treatments- Standard Matrix for Primary Roads in Bangladesh

Treatment alternatives	Standards [Roughness IRI]				
	A IRI=3	B IRI=3.5	C IRI=4	D IRI=4.5	E IRI=5
[1] RM + Seal coat	1A	1B	1C	1D	1E
[2] RM + DBST	2A	2B	2C	2D	2E
[3] RM + Carpeting	3A	3B	3C	3D	3E
[4] RM + Overlay 40mm	4A	4B	4C	4D	4E
[5] RM + Overlay 60mm	5A	5B	5C	5D	5E
[6] RM + Overlay 80mm	6A	6B	6C	6D	6E

In Khan (2005), determination of treatment intervention criteria was based on section optimization techniques. Several HDM-4 strategy analysis runs were made for several sections with different treatment intervention levels. Optimum maintenance standard was then selected as the one with the highest Net Present Value (NPV/cost).

The statistical “t” distribution at 90% confidence interval was also considered to determine optimum maintenance standard zone for each road group to obtain sound results. Any standard in this zone can be considered acceptable.

Engineering judgment was also applied to select the optimum maintenance standard when NPV/cost was the same among some standards for a road group. The judgment was based on road classification and their importance (Khan, 2005). The overall procedure followed to optimize maintenance standard is depicted in Figure 2.5.

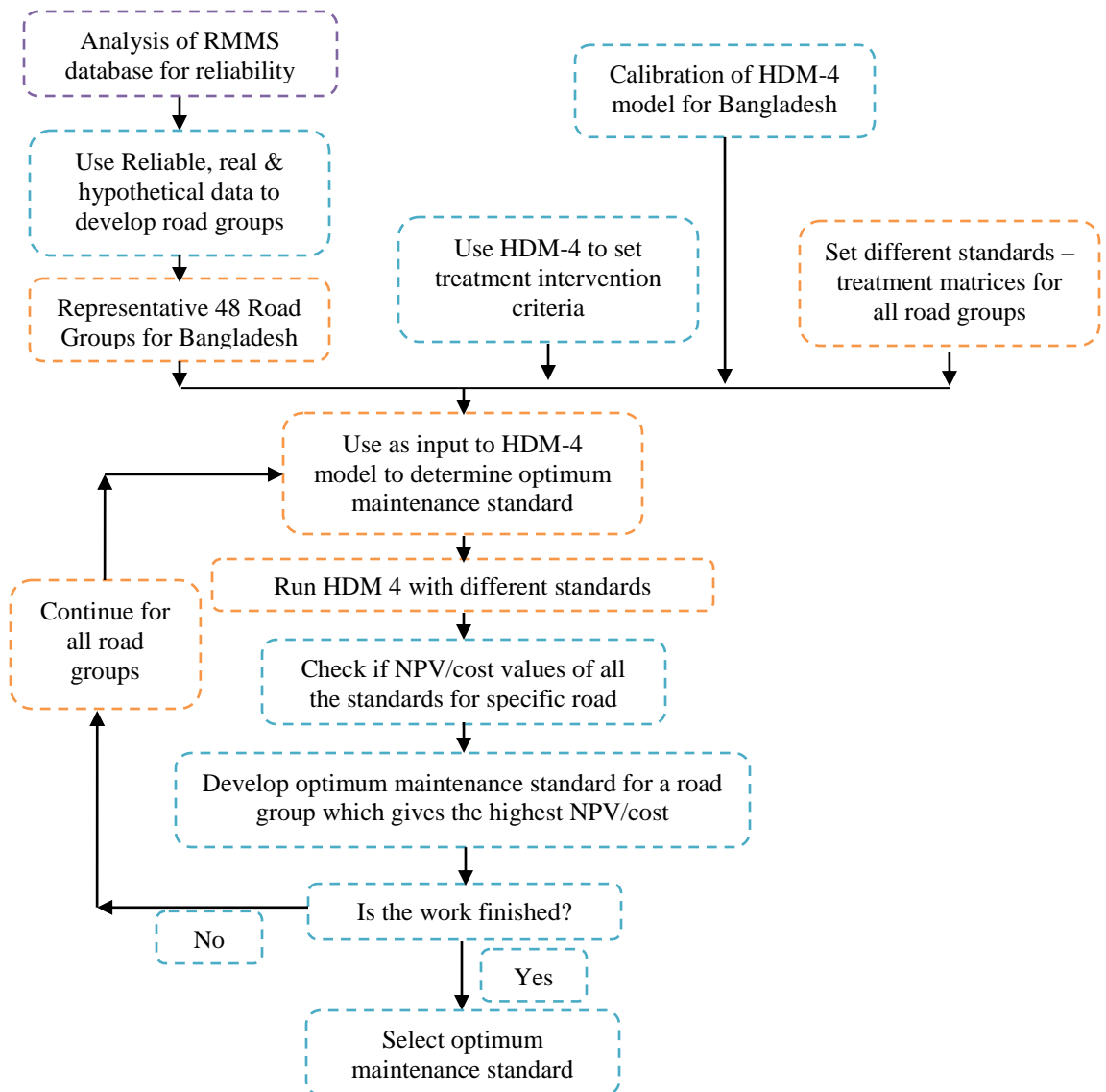


Figure 2.5 Methodology used to drive optimum maintenance standards using HDM-4model (Khan, 2005).

### 2.10.7. Life Time Pavement Performance & Optimized Budget

Once optimum maintenance strategies are determined, lifetime pavement performance and optimized budget of road network could be predicted from HDM4 analysis. Pavement performance curves under optimum maintenance standards in terms of road roughness (IRI) with time (ESAL) can be plotted. Figure 2.6 demonstrates pavement performance at optimum maintenance standard of asphalt concrete surface at medium traffic on two-lane two-lay roads in Bangladesh (Khan, 2005). The optimum maintenance strategies utilized were routine maintenance every year and overlay in 2004, in 2009 and 2017 as can be seen in Table 2.5.

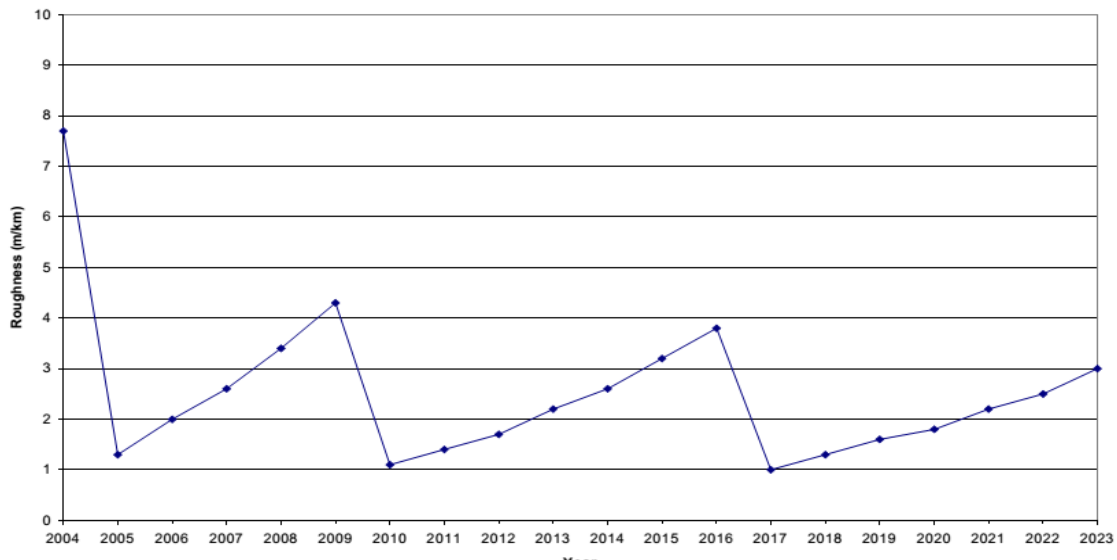


Figure 2.6: Pavement performance at optimum maintenance standard for ACMTT (Khan, 2005)

Once optimum maintenance standards are set, long-term budget forecast are also determined using the HDM-4 Model (Khan, 2005). Sample analysis of budget forecast under selected optimum maintenance standard for different road groups in Bangladesh as illustrated in table 5 (Khan 2005).

Table 2.5: Budget forecast for different type of roads in Bangladesh

Road Group	Name of Road Group	Optimum maintenance standard [IRI]	Treatment required to maintain the road at its standard	Budget Required (million Taka)	Maintenance strategy (RM : conducted every year)
ACMTT	Asphalt Concrete, Medium traffic & Two lane two way	4.39	RM + 80mm Overlay	19.5	80mm Overlay in 2004, 2009 & 2017
STLTST	Surface treatment, Low traffic & Sing lane Two way	5.50	RM+40mm Overlay	8.70	40mm Overlay in 2004,2009,2014 & 2020
STLTIT	Surface treatment, low traffic & Intermediate lane Two way	4.83	RM + Carpeting	6.20	Carpeting in 2004, 2008, 2012, 2016, 2021

### 2.10.8. Reliability of HDM-4

HDM4 models have been developed based on the studies conducted in several countries with varying road and traffic conditions. HDM-4 has proved suitable in a range of countries including Ethiopia. However, calibration of models to suit the local conditions improves its reliability. Reliability of results of HDM4 analysis depends on basically two things; how well the available data represent the real conditions and how well the Model's predictions fit the real behaviour and respond to prevailing conditions (Morosiuk et al, 2004). Finally as with any model, it needs to carefully check output with good judgments.

The accuracy and reliability of input data (road network & fleet characteristics, road surface conditions, utilization, etc) take the most important part of reliability of HDM 4 outputs. This requires correct interpretation of the input data requirements of HDM4 and a quality of input data appropriate for the desired reliability of results (Morosiuk et al, 2004).

Calibration requires adjusting model parameters to enhance the accuracy of its representation of local conditions. Different **levels** of calibration could be performed and mostly require selecting road section and monitoring the actual progress of different parameters. This allows adjusting what is predicted and what is actually observed.

Level 1 calibration determines required basic input parameters, adopts many default values, and calibrates the most sensitive parameters with best estimates, desk studies or minimal field surveys. Level 2 calibration measures key parameters and conducts limited field surveys makes measurements to verify and adjust predictions to local conditions. Level 2 requires moderate data collection and moderate precision and adjustments entered as input data, typically no software changes (Morosiuk et al, 2004).

Level 3 is called adaptation through major field surveys to re-quantify relationships. This requires establishing long-term monitoring structured research, advanced data collection. This is used to evaluate trends and interactions by observing performance over long time period and may lead to alternative local relationships/models (Morosiuk et al, 2004). Level 1 is required for all HDM4 analysis. If possible, a Level 2 calibration should be performed. It requires a higher degree of data collection and precision than in a level 1 calibration, and extends the scope. Detail on calibrating the model and the sensitivity of the main input parameters are discussed in Volume 5 of the HDM-4 (2004).

The study couldn't get any level 2 or level 3 calibration documents for Ethiopian case. Level 1 calibration is always utilized in ERA with data collected through desk study Conducting higher level of calibration would not be feasible to finish within the given thesis schedule. Hence, HDM4 version 1.1 currently in use by ERA along with actual data collected from ERA, document analysis, field observation and engineering judgment was utilized in the study.

## 2.11. Summary of Literature and Research Aims

Overloading has several impacts on economy, and efficiency of road infrastructure. Overloading has also impact on environment, safety and fair trade. Economic impacts of overloading include; increase in vehicle operating costs, increase in maintenance costs and reduced pavement life.

Vehicle operators' lack of awareness regarding pavement damage due to overloading and reluctance to self regulate due to their desire to make more profit from extra loading was considered primary cause for overloading. The weak road management system in developing countries was also considered a reason for increased overloading activity. Overload fines imposed by courts was considered insufficient and ineffective in preventing overloading because they are unrealistic and low compared with the damage done by the vehicle on the road and the higher profit made by the hauler in transporting a heavier load.

The best alternative recommended for governments to deal with overloading was maintaining roads to desired level of service combined with strict law enforcement. The importance of efficient road management system was also given more emphasis in overload control. Literatures also show that importance of enforcement or penalty was similar in terms of overload prevention. However increasing overload fine supplemented by enforcement was considered cost effective mechanism of overload control.

Determination of a rational overload fine that commensurate the actual damage to the pavement requires analyzing damage related with overloaded truck. Literatures recommend for efficient pavement management system to optimize and justify maintenance strategies of pavements and analyze life cycle economic impact of overloading.

Computer software, Highway Design and Management Model (HDM-4), was used to assist the determination of optimum strategies, predict pavement performance and optimized budget for deferent road classes. Optimum road works were primarily selected considering feasibility from technical point of view that yields maximum NPV/cost ratio and realistic results over analysis period. The difference in net present value between case traffic with overloading and normal traffic was considered as economic impact due to overloading. Estimated economic impact due to overloading can be finally added to weighing stations cost and used to determine of rational overload fine.

### 3. RESEARCH METHODOLOGY

#### 3.1. Introduction

The methodology used in this study is divided into three basic sections. These are data collection, overload charge analysis and comparison of rationalized overload fine with court imposed overload charges. Details are presented in the following sections.

#### 3.2. Data Collection

Both primary and secondary data were utilised in the study.

##### 3.2.1. Data Classification

(i) Axle load related data was collected through:

- Document analysis; 2013 Secondary data of Modjo and Awash weighing station; and
- Field Survey: Two directional heavy vehicles and Truck and Trailers axle load survey was also conducted at Modjo weighing station. Axle Load data collection format is presented in Appendix A.

(ii) Weighing stations cost related data was collected through:

- Document Analysis; Operation manual of AAAEW weighing station, and ongoing weighing station projects of ERA Axle Load Management Section.
- Field Observation; At Modjo and AAAEW weighing stations.

(iii) Court Overload Fine related data was collected through:

- Document Analysis; Sample court overload cases and their corresponding overload charge were collected from Modjo weighing station.

(iv) Road Network related data was collected through:

- Document Analysis; As Built Pavement Report, Geometric Design report, Soil and Material Report, Geotechnical Report and other documents of AAAEW.
- Field Visit; Field trip and observation of entire study road sections of AAAEW

(v) Traffic data was collected through:

- Document analysis; secondary data from traffic survey conducted by SCOTT WILSON Company and as built pavement report of AAAEW (2014).

(vi) Vehicle Characteristics, road user related data was collected through:

- Secondary data; Economic and Financial Vehicle Operating Costs and related Parameters of ERA Roads Economic Section

(vii) Maintenance Standards and Cost related data was collected through:

- Secondary data; ERA Roads Economic Section, AACRA Roads Maintenance Section
  - Document Analysis; Contract prices of Contractors and Consultants

### 3.2.2. Sample Size

The required sample size [n] for axle load survey depends on: variance or heterogeneity of population, the degree of acceptable error, and confidence level (Cochran, 1977). Equation 3.1 (estimation of sample size by proportion) was used to estimate sample size (n) of the number of overloaded vehicles considered in this study.

$$n = \frac{Z^2 * p * q}{(ME)^2} \dots\dots\dots 3.1$$

Where

- Z: desired confidence interval
- P: proportion of population with desired output and q=1-p
- ME: margin of error which denotes the accuracy.

If prior information is available concerning the value of p to calculate n or if no prior information about p is available to obtain a conservative estimate, p = q = 1/2 is used to estimate the required sample size..

The confidence interval was selected to be 90% (Z =1.65) and the margin of error was selected as 5%. According to Africon (2011) Report, 15-20% of the heavy vehicles were expected to be overloaded. Hence, the sample size was calculated with proportions of p=15% and p=20%. The maximum of the two sample sizes was then used for the study. Using equation 3.1, p = 15% provides sample size of 139 and p = 20% provides sample size of 174. Accordingly, the minimum sample size was taken as 174 heavy trucks.

### 3.2.3. Study Area

The selected study area is the Addis Ababa – Adama Expressway road link. The road is located along the Addis Ababa - Djibouti Road, which is a major gateway of Ethiopia's import-export logistic and it is expected that heavy vehicles will remain a common sight on the expressway in the future. In the past five years, a total of 884,290 axles have been weighed at the Awash Weighing Station. Out of these 1-2% of front axles and 5-20% of rear axles were overloaded. Therefore, overloading is serious on the Study Area. The project selection is rational due to its recent nature and availability of road design documents.

Five road sections were established for the Study considering traffic homogeneity and topographic characteristics. The two directions of study road link were also considered separately due to their differences in traffic volume and terrain. Hence; separate road networks, one uphill (Adama to Addis Ababa) and second downhill (Addis Ababa to Adama), each comprising five sections, were developed for analysis using HDM-4 Detail of the study sections are discussed in Section 5.2.1.

### **3.2.4. Sampling Technique and Reliability of Data**

Most data used for this study were collected from reliable secondary sources and through field survey. The sampling procedure used to obtain axle load and court-imposed overload fines was also random.

Sample Axle Load survey was also conducted on working days specifically on November, 22, 2014. The survey started in the morning at 8:30 am and went on throughout the day until the required number of samples was collected. Axle load surveys were conducted only on vehicles with prevailing procedure carrying weight beyond 7.5 ton. During the survey, heavy vehicles and truck and trailers were diverted and weighed at Modjo Weighing Station. Other vehicles were assumed less likely to overload and hence were not considered.

Modjo weighing station was selected due to the location of weighing station with respect to the study area. The weighing station is located in Modjo town roughly 50 km from Addis Ababa. Hence, it is considered an ideal location to provide representative overload pattern of the entire AAAEW road sections. All overloaded trucks are denied access to the Expressway and usually use the old Addis Ababa - Adama road. The Modjo weighing station is the only fixed weighing station to control this overloaded trucks.

### 3.3. Data Analysis

#### 3.3.1. Overload Pattern and Overload Cases

In order to analyse the economic impact of overloaded trucks, which is the base for determining overload fine structure, overloaded trucks were ideally allowed to use the road. In reality not every axle is overloaded and overloading rate is also not constant among vehicles or axles. Hence, statistical analysis of axle load data of Modjo weighing and field axle load survey was performed to determine overload pattern of two vehicle types. Proportion of overloaded trucks and overload pattern among vehicles used for this study is discussed in section 4.7.1.

Five overload cases were identified to levy different overload fines based on the severity of overloading per axle. These five cases are truck traffic comprising overloading per axle of 10%, 20%, 30%, 40% and 50%. The 10% interval was selected based on aggregate data collection formats used in the Axle Load Management Section of the ERA. Percent of overloading per axle was used due to the same relative damage for front and rear axles relative to their legal limit as discussed in section 4.7.2.

Each overload case permit different rate of overloading as discussed below.

- **Case 0** (normal traffic); represents the traffic used in pavement design. Each section is assigned with normal traffic and truck factor as given in as built pavement design report of AAAEW (2014). Case 0 served as a reference to evaluate economic loss due to overloaded trucks.
- **Case 1:** Allows trucks with up to 10% overloading per axle to use the road without unloading extra weight in addition to normal traffic.
- **Case 2:** Allows trucks with up to 20% overloading per axle to use the road without unloading extra weight. This includes the normal traffic, trucks overloaded up to 10% per axle and trucks overloaded up to 20% per axle.
- **Case 3:** Allows trucks with up to 30% overloading per axle to use the road without unloading extra weight. This includes the normal traffic, trucks overloaded up to 10% per axle, trucks overloaded up to 20% per axle, and trucks overloaded up to 30% per axle.
- **Case 4:** Allows trucks with up to 40% overloading per axle to use the road without unloading extra weight. This includes the normal traffic, trucks overloaded up to 10% per axle, trucks overloaded up to 20% per axle, trucks overloaded up to 30% per axle and trucks overloaded up to 40% per axle.
- **Case 5:** Allows trucks with up to 50% overloading per axle to use the road without unloading extra weight. This includes the normal traffic, trucks overloaded up to 10% per axle, trucks overloaded up to 20% per axle, trucks overloaded up to 30% per axle, trucks overloaded up to 40% per axle and trucks overloaded up to 50% per axle.

Summary of overload cases considered in study is presented in Table 3.1.

Table 3.1 Overload Cases used for the study

Overloading per axle	Overloading Cases					
	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
≤0 % (without Overloading)	√	√	√	√	√	√
0-10%	×	√	√	√	√	√
11-20%	×	×	√	√	√	√
21-30%	×	×	×	√	√	√
31-40%	×	×	×	×	√	√
41-50%	×	×	×	×	×	√

Note:√: Truck Can use the road

×: Truck has to unload extra weight to the nearest limit before using the road

The traffic for overloaded cases was estimated using the proportion of overloaded trucks expected to use the road. The traffic comprises normal trucks, overloaded trucks and generated trucks. Extra weight from vehicles that overload beyond particular case under study was assumed to be transported using extra vehicles that would generate additional traffic to the annual AADT. These vehicles were predicted by estimating the number of vehicles required to transport extra weight. The generated traffic was assumed to have similar truck factor as normal truck used to transport extra weight. Details of traffic prediction for each overload case are discussed in section 5.2.7.

From observation of weighing stations, overloaded vehicles usually unload (adjust) extra weight to the nearest legal limit, to reduce cost of unloading. Accordingly, overloaded trucks beyond particular case were unloaded to the maximum allowed overload case under consideration before using the road. Their truck factor after unloading extra weight was taken as similar to truck factor of maximum overload case under consideration. For example overload case 2 allows only up to 20% overloading per axle to use the road. If a vehicle is 30 % overloaded per axle, it has to unload extra weight to the maximum permitted overloading of 20% under case 2. The equivalent axle load factors of overloaded after unloading extra weight was then assumed to be similar to maximum permitted overload per axle, in this case the same as 20% overloaded trucks.

Truck factor of overloaded vehicles also vary among overloaded cases. For normal traffic, truck factors recommended as built pavement design report of AAEW were assigned. For the remaining overloaded cases, the truck factor was determined using equation 5.4.

### 3.3.2. Court Imposed Overload Fines

Court-imposed overload charges of Modjo weighing station were analysed. Statistical analysis shows a widely scattered overload fine versus gross overload weight per vehicle. Detail of statistical analysis of Modjo weighing station data is discussed in Section 4.7.

### 3.3.3. Determination of Economic Impact of Overloading

Lifecycle HDM-4 Programme Analysis was performed to determine economic loss as a result of overloading. A separate HDM-4 analysis was performed for each overload case. For normal traffic, the expressway is expected to last its design period of 20 years with normal maintenance strategies predicted in the feasibility study of the road. Whereas for overloaded cases, the actual pavement life would be less than 20 years and rehabilitation could be recommended before the end of analysis period of 20 years. However, this would mean no periodic maintenance or pavement strengthening work was performed on pavement prior to reconstruction. Even if the life is less than the design period, the option is still open; because, an overlay at a later date will bring the serviceability index up and extend the life of the pavement to desired 20 years.

In this study, the same analysis period of 20 years was maintained for all overload cases. Different thicknesses of structural overlay alternatives were also applied when the pavement reached a certain level of road roughness (IRI). The corresponding road user costs such as VOC and travel time costs were also predicted. The combined result of Programme Analysis was finally expressed in terms of NPV. The overall procedure followed in HDM-4 analysis is as presented below:

- **Defining the study networks, sections and related section data;** twelve road networks (six overload cases in two directions of traffic) each with five road sections were created. Traffic and vehicle fleets, and general data requirements applicable in study area were also created for each section. Condition of entire road network was considered the same as new road in year 2014. HDM-4 configuration was also taken into account during data input.
- **Developing maintenance strategies, cost estimates, and life expectancy;** Routine and periodic Maintenance standards that are common in Ethiopia were considered for the study. Non-pavement routine maintenance works were applied annually. Pavement related routine maintenance and periodic maintenance works were applied based on condition of pavement. IRI values in the range of 3m/km-5m/km at 0.5m/km interval was used as a trigger values for periodic maintenance. Economic and financial cost of all maintenance types was obtained from ERA, AACRA and private contractors in Ethiopia. Other coefficients related to effect of road works and road deterioration models were used as default values specified in HDM-4.

- **Optimizing Maintenance Work;** It was not possible to find optimized maintenance standards of AAAEW. Accordingly, optimization of maintenance standard for AAAEW Road Link was performed prior to estimating associated NPV over analysis period of 20 years. A matrix of alternative maintenance standards of routine maintenance and periodic maintenance at different roughness values (IRI) was developed.

Optimized maintenance standard for particular road section under particular overload case was primarily selected based on maximizing NPV/C principle (maximizing economic benefits). In addition, engineering judgments were used to check reliability of outcomes of HDM-4.

Accordingly, overall maintenance need of each section in the road link under consideration was analyzed. Detail of maintenance standard alternatives, optimization and corresponding NPV/C estimation is discussed in Section 5.3.

- **Future pavement performance and NPV;** Lifecycle HDM-4 Programme Analysis of AAAEW road link was performed using HDM 4 version 1.1 and optimized maintenance standards. Accordingly future pavement performance and associated NPV of each section under each overloading case were determined.

The net present value (NPV) of investment cost of overloaded cases was determined for each overloading case and the reference Case 0. The difference in NPV of each overloading cases with respect to the reference case (normal traffic) was considered as economic loss due to overloading.

### **3.3.4. Weighing Stations Cost**

If every truck respected the regulated axle load limits, axle load control wouldn't be necessary. However, the opposite is practiced by truck operators and so control is required. Hence, initial investment and operational cost of weighing stations was included as part of overload fine analysis since it represents cost to the owner of the infrastructure.

Prediction of weighing station infrastructure and management cost was estimated based on existing cost of the Modjo Weighing Station and the AAAEW weighing stations and data from ERA road asset management section. Detail weighing management cost is discussed in Section 5.3.10.

### **3.3.5. Rationalized Overload Fine and Comparison with Court Imposed Overload Fine**

The rationalized overload fee includes both economic loss due to overloading and overhead cost of the weighing stations. Economic loss due to overloading of each case was primarily distributed to overloaded axles under each case. Sequential analysis was performed in determining economic loss per percent of overloading per axle as shown in Figure 3.1.

First, economic loss due to overloaded trucks under Case 1(10% overloaded axles) was distributed to the total number of overloaded axles under Case 1. Accordingly, the economic loss per 10% overloaded axle was determined. This in turn helps to determine economic loss per axle of the next case.

The total number of 10% overloaded axles and their cost under Case 2 were multiplied by economic loss per 10% overloaded axle (already determined) to get the contribution of 10% overloaded axles under Case 2. Economic loss due to 10% trucks overloaded under Case 2 was then subtracted from total economic loss of Case 2 to determine the net economic loss attributed to 20% overloaded axles. This net economic loss due to 20% overloaded axles was then distributed to total number of 20% overloaded axles and economic loss per 20 % overloaded axle was determined. This will in turn serve as an input to determine cost per 30% overloaded axle under case 3. A similar procedure was followed for the remaining cases. Finally economic loss per 10%, 20%, 30%, 40% and 50% overloading per axle were determined.

Estimated overload management costs of the weighing stations were distributed equally to total number of overloaded axles.

Finally the economic loss per percent of overloading per axle was added to the overload management fines per axle to determine overload fine per axle.

Sample court-imposed overload fines were analyzed and compared with the rationalised overload fine. Findings in this regard are discussed, and summarized under conclusions and recommendations

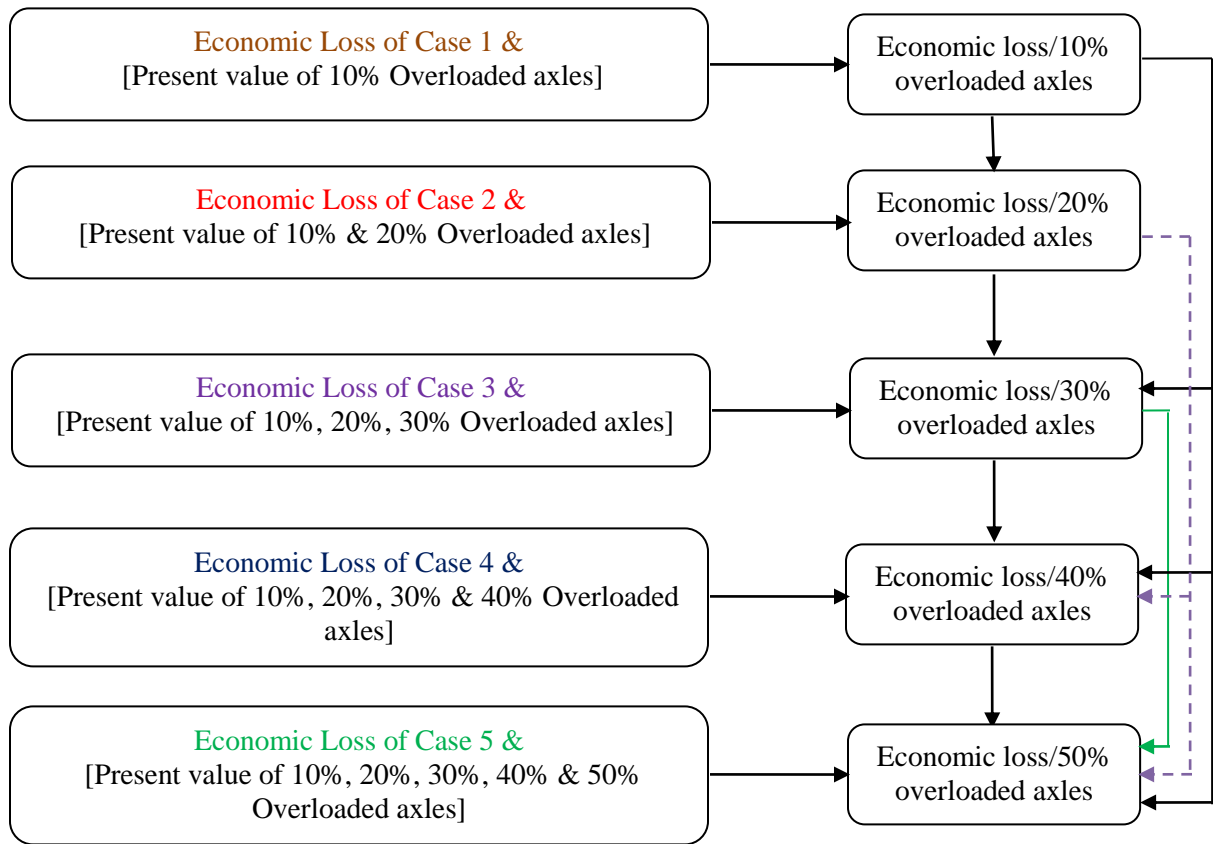


Figure 3.1 Procedure of Distribution of Economic loss due to overloading to overloaded axles

### 3.4. Limitation of the Study

The following are limitations of this study:

- Due to time and budget limitations, secondary data of traffic, weighing stations and road user economic were used in the analysis.
- The study largely depends on HDM 4 capability for predicting road deterioration for various overloading cases. Hence the impact of overloading on bridges was not considered as part of overload fine analysis. Overload damage analysis to determine the weighing tolerance and the impact of overload on safety are beyond the scope of this study and hence were not considered.
- Benefit of overloading was considered during HDM-4 only in terms of extra weight on overloaded trucks. However, other economic benefits of overloading were not considered.

### 3.5. Summary of Methodology

Summary of the methodology used for this study is presented in figure 3.2.

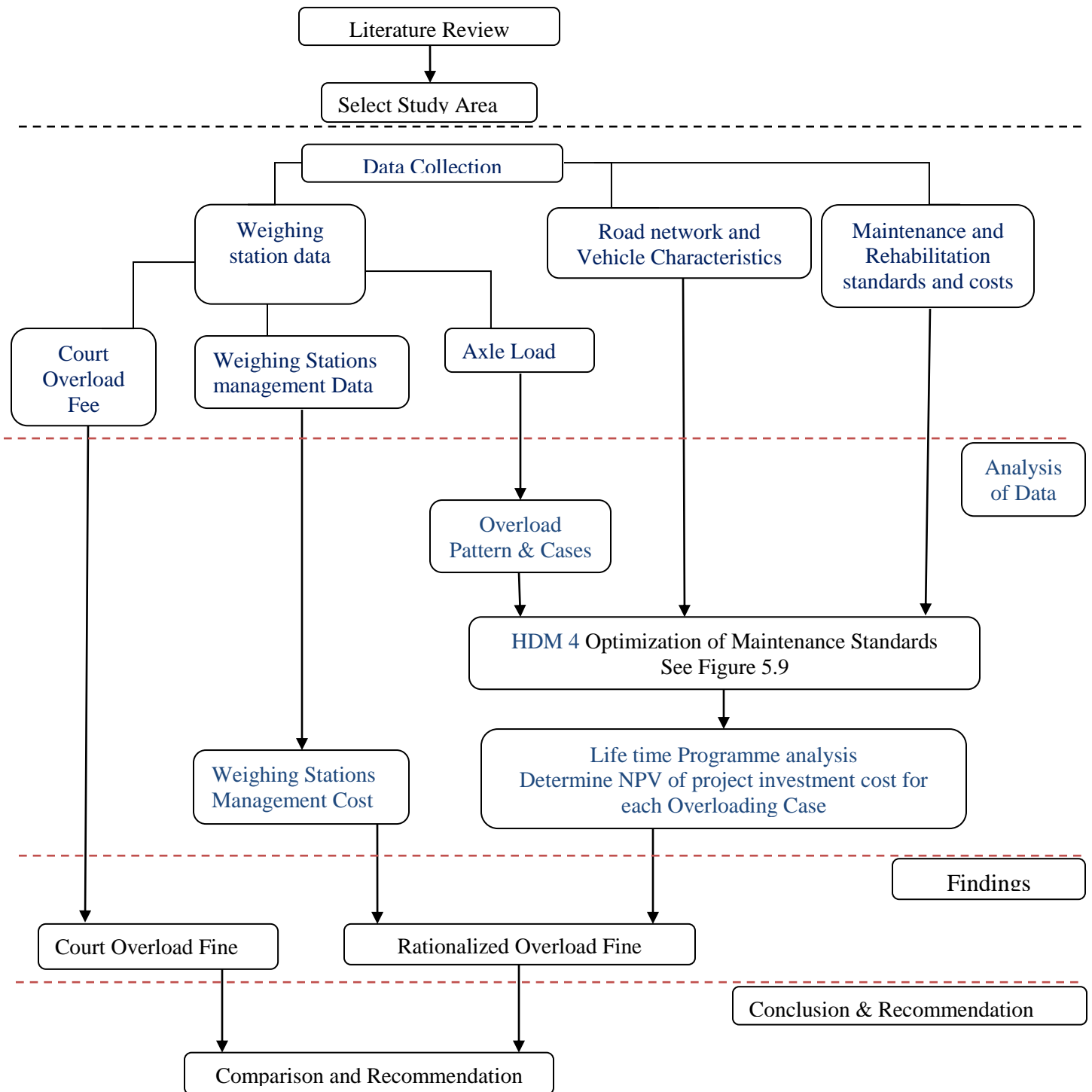


Figure 3.2 Summary of Methodology Used for the Study

### **3.6. Summary of Findings**

Rationalized overload fine structure (price/ overload/ km) was prepared considering Overload pattern with corresponding economic impact and weighing stations cost. Statistical comparison between rationalized overload fines indicates a significant difference in terms of individual fines. The gross revenue collected by court from sampled overloaded trucks was also lower than what could have been collected using rationalized overload fines.

## 4. OVERLOAD MANAGEMENT IN ETHIOPIA

### 4.1. Axle Load and Vehicle Size Limits of Ethiopia

The current axle load limit regulation is based on a proclamation that was enacted in September 1990 under publication of Negarit Gazeta. Eight (8) Basic Articles are stated under the council of ministers regulation N<sup>o</sup> 11/1990 entitled “Council of ministers regulation to amend the vehicle size and weight regulations”. Table 4.1 and Table 4.2 present summary of the regulation on vehicle size and weight (Ethiopia Council of Ministers, 1990)

Table 4.1 Restriction to Vehicle size

N <sup>o</sup>	Description	Limit
1	Total <b>width</b> of any vehicle including load thereon	$\leq 2.5m$
2	Total <b>Height</b> of any vehicle including load thereon	$\leq 4.2m$
3	Total <b>Length</b> of any <b>single</b> vehicle	$\leq 12m$
4	Total <b>Length</b> of any <b>combination [Truck Trailer   semitrailer]</b> vehicle	$\leq 17m$
5	Total <b>Length</b> of any <b>combination [Truck with drawbar Trailer ]</b> vehicle	$\leq 18m$
6	Combination of Motor Vehicles	$\leq 2units$

Table 4.2: Restriction as to weight of Vehicle

N <sup>o</sup>	Description	Limit
1	Steering Axle   Single Axle Single Wheel	$\leq 8 tons$
2	Single Axle dual Wheel	$\leq 10 tons$
3	Tandem Axle dual Wheel [C/C spacing between axles <1.3m]	$\leq 17 tons$
4	Tridem or more axles, load per axle <b>If C/C spacing between axles &gt;1.3m</b> Load per single Axle	$\leq 10 tons$

**Note:** Spacing of axles is measured longitudinally between centers of axles

Any vehicle beyond the specified limits must get a special permit. In actual practice there is no consideration in axle spacing in axle weighing station. A simple rule of 8 ton on front axle and 10 ton on rear axle were applied as legal limits. Hence a 20 ton on tandem axle or 30 ton on Tridem axle is considered legal regardless of axle spacing. In this study 8 ton on front axle and 10 ton on rear axle are considered as a legal axle load limits from practical point of view.

## 4.2. Axle Load Limits of Regional Countries

The Ethiopian axle weight regulation is not harmonized with the axle load limits of regional countries and recommendations of the Southern African Development Community (SADC). The axle load limits of Ethiopia, neighbouring countries and regional offices are shown in Table 4.3.

Table 4.3: Variation of vehicle load limits in COMESA Countries (Michael Ian Pinard, 2010)

Countries by region	Steering axle (tons)		Non Steering axle (tons)								Permissible Maximum combination mass (tons)
	Single	Tande m	Single		Tandem		Tridem		Quandem		
	2 tyre	4 tyre	2 tyre	4 tyre	4 tyre	8 tyre	6 tyre	12 tyre	8 tyre	16 tyre	
COMESA	8	-	8	10	16	16	24	24	-	-	53
Burundi	8	-	-	10	-	16	-	24	24	32	NA
Djibouti	6	-	-	8	-	16	-	24	-	-	46
Ethiopia	8	-	-	10	-	17	-	24	-	-	-
Eritrea	6	-	-	8	-	16	-	24	-	-	46
Kenya	8	-	6	10	12	16	18	24	-	-	53
Sudan	7.7	-	-	10	-	16	-	22	-	-	46
Uganda	8	14	8	10	12	16	18	24	24	32	46
Rwanda	8	-	-	10	-	16	18	24	24	32	NA

NA: not applicable

The comparison between various COMESA countries in Table 4.3 indicates some variations on their axle load limits. Especially Djibouti and Eritrea have lower axle load limits while the remaining countries have similar axle load limits. Lack of harmonization creates a trade logistic barrier to transporters. Several containers will be accumulated at ports due to variation of axle load limits. This could expose transporters and countries to additional cost. Therefore axle load harmonization among regional countries within the continent should prevail for economic unity of the continent in general.

### 4.3. Weighing Tolerance

Due to scale errors and other external factors contributing towards the accuracy of weighing systems, no systems can be totally accurate all the time. For the above reasons, some tolerance in the weighing measurement is normally made in the form of a weighing tolerance. The magnitude of such an allowance is based on the assumed scale error (scale type dependent) plus that estimated for external factors (Intercontinental consultants and Technocrats Pvt. Ltd, 2011).

In order to ascertain a reasonable basis for setting a weighing tolerance, a National Weighbridge Survey was carried out in South Africa in 2002, in which 57 weighbridges were used (single axle scales, axle unit scales and multi-deck scales) to weigh a multi-axle vehicle that had been previously weight-sized (Intercontinental consultants and Technocrats Pvt. Ltd, 2011). The survey found that:

- Gross Vehicle Mass: All readings fell within the range  $-0.88\%$  to  $+0.76\%$  of the average combination mass;
- Axle Unit: All readings fell within the range  $-2.14\%$  to  $+2.78\%$  of the average combination mass; and
- Steering Axle: All readings fell within the range  $-5.12\%$  to  $+4.96\%$  of the average steering axle mass.

Based on the above findings, it was recommended that the tolerance on GVM should be set at  $\pm 2\%$  and that on axles at  $\pm 5\%$ . It was also agreed at a tripartite (SADC/COMESA/EAC). Regional Workshop on Harmonization of Key Elements of Best Practice in Overload Control (Infra Africa (Pty) Ltd, 2008) recommends that, as an interim measure, a mass tolerance of 5% on axles, axle units and GVM would be adopted. However, the study couldn't find any legal document on tolerance to axle or vehicle weight of Ethiopia.

#### 4.4. Reasons for Overloading

Being the main route between Ethiopia and Djibouti Port, a significant number of heavy trucks use the Addis Ababa - Djibouti road corridor every day. The economic growth in recent year has also increased not only the normal freight demand but also unconventional loads. The lack of balance between freight demand and supply, lack of awareness on overloading, transporters' competition to make more profit, and the ineffectiveness of overload management system are the main reasons behind increasing overloading activities along the corridor.

The first reason is related to lack of sufficient quantity and quality of trucks. Economic growth results in higher freight demand. However, transporters lack the capacity to adjust their services in terms of number and quality, of heavy vehicles to satisfy the freight demand. As a result, the effort to transport as much load as possible in a single trip and to make disproportionate profit would result in overloaded trucks. They are also lack special vehicles that are required to transport unconventional loads. Old trucks with fewer numbers of axles are usually overloaded on their axles.

For some drivers, first time they stopped, overloading is an honest mistake. There is also misinterpretation among drivers and vehicle operators on axle load limits. Transporters lack sufficient awareness regarding the damaging impact of overloaded trucks on road and bridge structures. They don't have a scientific mechanism to select appropriate vehicle and adjust their gross load within legal axle load limits.

On the other hand, some operators have adopted themselves toward overloading. If the benefit from extra weight is higher than low and inconsistent court fee, vehicle operators may prefer to overload. Some vehicle operators even believe that they can't make profit without overloading and results in unfair competition among transporters that put legal transporters at risk and increase overloading activity.

Finally the road network management lacks efficiency in preventing overloading. Most of the heavy vehicles are checked at fixed weighing stations. Overloaded trucks change route to avoid weighing stations, or travel across the weighing station at night without stopping or create a way out of the manual weighing system. The lack of mobile units that track overloaded trucks that avoid weighing stations, manual recording of weighing stations, and lack of rational fine penalty and the overall inefficiency of overload management system makes it difficult to prevent overloading.

## 4.5. Weighing Stations and Overload management

### 4.5.1. Weighing Stations

The major freight corridors have to be considered in selecting locations of fixed weigh bridge. Roads that provide access to ports in neighbouring countries require weighing bridges at specific location. Besides, cost benefit analysis can be performed for optimal weigh bridge locations. The Addis-Djibouti road is the main gateway of import-export goods of Ethiopia. Hence it is susceptible to overloading from heavy traffic plying on this route.

Weighing bridges across the country are currently administered by ERAs Road Asset Management Section. There are nine stationery weighing bridges most of which are installed at “strategically important places” all over the country (Intercontinental consultants and Technocrats Pvt. Ltd, 2011). Additional three mobile weighbridge teams have been introduced for random axle load control at different locations through in the country. Besides, there were three weighing bridges under construction at Semera, Sendafa and Woreta during this study (Intercontinental consultants and Technocrats Pvt. Ltd, 2011).



Figure 4.1 Location of Weighing bridge Stations Existing and Proposed (Intercontinental consultants and Technocrats Pvt. Ltd, 2011)

Additional weighing stations were recommended as indicated in Figure 4.1. The recommendation for locations of weighing bridges was not based on scientific approach selecting appropriate location of weighing station. It was chosen considering the possibility of intercepting overloaded vehicles. As literatures recommend, the appropriate location should be based on feasibility studies of weighing stations at different locations.

In this study, the Modjo Weighing Station was utilized as sources of data. The selection is based on its proximity to the study area (AAA EW). As the weighing station is located on the way from Addis Ababa to Adama, it was believed that it would provide the desired overload trend on Addis Adama Road.

#### **4.5.2. Overload Management**

The Ethiopian roads Authority under Ministry of Transport has the authority to stop and measure any vehicle at weight bridge stations. The current practice at weighing station requires heavy vehicles heavier than 7.5 tonnes to be weighed. Where a transport warden or traffic police officer upon weighing a laden vehicle finds the weight to be in excess of the limits, he shall then require the removal of the excess weight in the nearest town up to the limit permitted by the regulation (Ethiopia Council of Ministers, 1990) . The transport warden or traffic police officer has no responsibility for the safety of anything unloaded (Ethiopia Council of Ministers, 1990). Where a vehicle is found not to comply with the provisions of this regulation, the transport warden or traffic police officer, before allowing the vehicle to proceed, shall make a full note of the inspection together with the plate number and the names of the owners and the driver of such vehicle and shall inform the driver that will be persecuted for contravention of these regulations (Department of Transport Directorate, 1997).

In order to understand the operational mechanisms, observation was made at Modjo Weighing Station. Heavy vehicles in both directions were stopped and weighed at this station. The practiced legal axle load limits are 8 tons on front axle and 10 tons on rear axle. The weighing machine is Electro-Mechanical type. However recording is taken manually by transport warden. The man dependency of recording was exposed to misreporting. Routine maintenance of weighing machine is carried out every three months and calibration is done annually in the presence of the professionals of quality and Standard Authority, Ethiopia.

Overloaded vehicles carrying loads that could be unloaded, such as sand, packed food etc, were unloaded to the safe limit. However, loads such as chemicals and machineries were allowed to proceed their journeys with especial permits. Overloaded vehicle operator license or plate was taken temporarily and was charged in the local court (Woreda). Depending on the cumulative amount of overloading per vehicle, the court imposes fine. The vehicle operators pay the amount specified by court to the local court and receive a receipt. Vehicle operators can then take back their license or plate after showing the proof of payment.

### 4.5.3. Court Imposed Overload Fines

According to the regulation, a vehicle which is found not to comply with the provisions of the regulation, the transport warden or traffic police officer, before allowing the vehicle to proceed, shall make a full note of the inspection together with the plate number and the name, owner and the driver of such vehicle and shall inform the driver that he will be persecuted for contravention of these regulations (Ethiopia Council of Ministers, 1990).

The real practice at Modjo weighing station is presented in this study. A vehicle in excess of the specified axle load limit is forced to stop around weighing station. Excess load is unloaded / adjusted to the legal limit. The transport warden will take record of measured weights of all axles. If regulation is violated, driver license or vehicle plate number is temporarily taken and the vehicle operator is charged at local (Woreda) Court. The court will hear the case and provide decision. The decision is for the vehicle operator to pay certain amount of money based sum overload weight on axles on a vehicle. The practice to use local (Woreda) court to decide on matters of overloading is similar across all weighing stations of Ethiopia, however the study couldn't find guideline for specifying overload fines.

**Figure 4.2** shows plot of gross overload per vehicle in quintals Vs court imposed overload fines of September 2014. Generally the scatter data shows a positive relationship between overload Gross vehicle overload and overload fine imposed by court. However court imposed overload fine is highly scattered

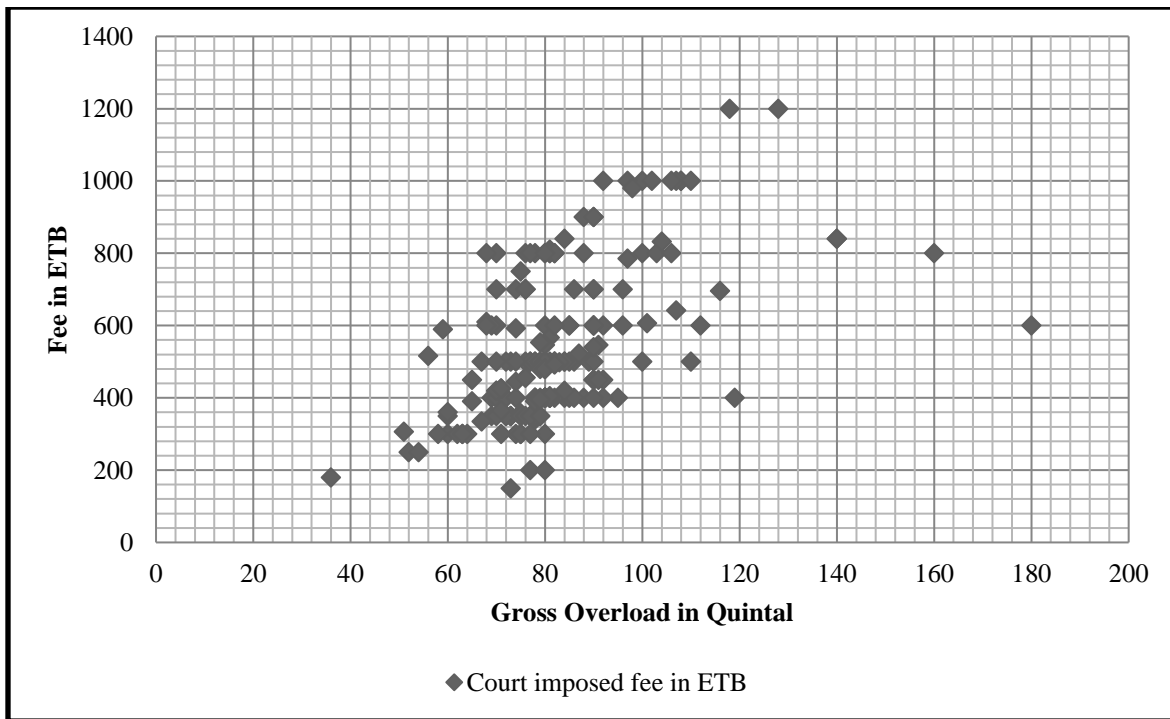


Figure 4.2 Court Imposed Fee at Modjo Weighing Station (September 2014)

The current practice of using court system has three major problems and all problems are illustrated with examples. The first problem is associated with the lack of a justification for establishment of court fee. There is no justification that shows the amount of fee is commensurate to the amount of damage done to the road infrastructure. This has resulted in inconsistency among court decisions by laying different charges to similar cases.

The second major problem is the time it takes for the court to process and reach decision. In this regard, overloaded vehicles are parked from hours to days before the court decision is made; then, vehicle operators pay the court order amount, recover their documents from weighing stations and finally continue their journeys. Several drivers don't pay the specified charges in the same month. According to the sample data, the number of days range from few hours to 6 months (vehicle operators' own problem). Even if the driver pays the charge on the same day, the vehicles remain parked on average for hours. Multiplying wasted days by time value of money results in high economic loss to the vehicle operator.

The third problem is related to payments; the money is paid to the court, not to the road management section. The road asset is controlled by a different organisation whereas the overload payment is made to a local court. Hence the revenue from overloaded trucks is not available for road maintenance and rehabilitation purposes.

One good practice observed from recording format is recording of operators' and drivers' names. This allows identifying vehicle operators who frequently and intentionally overload. The punishment for such operators could be severe compared to first timers.

#### 4.5.4. Special Permits

Construction companies and industries usually transport some kind of unconventional freight. Some loads are usually assembled machineries and hence extra weights can't be unloaded to a legal load limit unless the load is dismantled. Under such condition, interested companies submit request for special permit to the ERA Axle Load Management Section.

The service and special permit is given free of charge. There is no standard application format; however, it is usually required to include vehicle type, number of axles, and total weight of freight to be transported and selected route for transportation. The applications are processed through professionals at ERA Road Asset Management Section.

They basically distribute the total weight to number of axles based on experience and check if each axle's weights are within one ton off specified limit. Besides, the importance of the freight to the national interest is also another criterion. If a special vehicle with different size than specified in the regulation is to be used, it is checked for geometric characteristics of the road. Re-routing vehicle path will be designed for this purpose. The special permit is then finally approved or rejected by Director General of ERA. If the special permit is granted, the transporter will take full responsibility for any damage caused to the road.

The overall procedure for special permit is summarized in Figure 4.3.

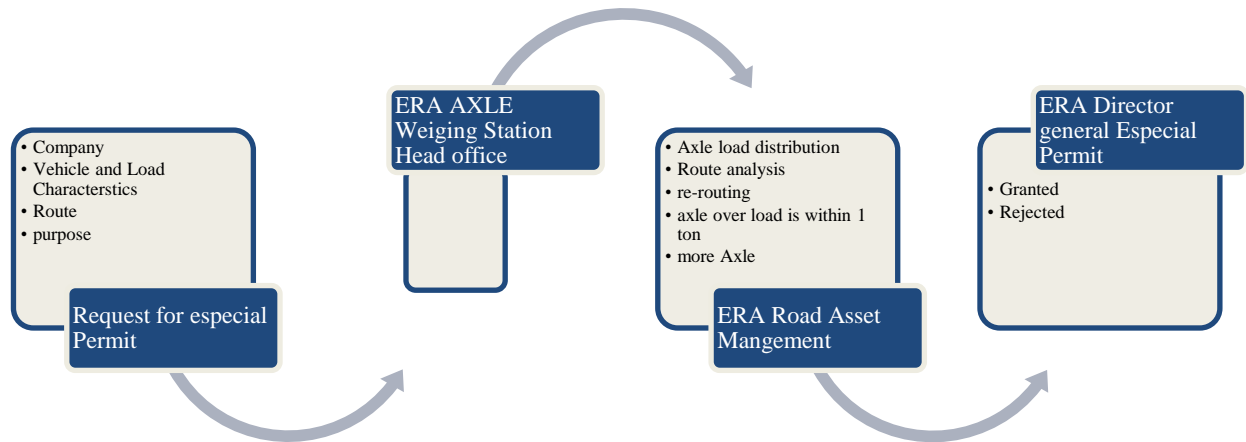


Figure 4.3 Overall Process for especial Permit

Request for special permit is required for every trip a vehicle makes. This is logical as the geometric elements of the road, capacity of bridges, pavements and the vehicle characteristics may vary. This approach is fair from protecting the road infrastructure point of view. The study couldn't find a written permit given to industries and private companies. However, two Permissions granted at the time of this study were obtained.

The first case is, starting from February, 18, 2013; the ministry of transport of Ethiopia has made temporary changes to axle load limits on Ethio- Djibouti road. The changes were justified to facilitate multimodal transport and as a solution towards reducing the number of containers at Djibouti port. The changes include, change of rear axle load limit from 10 ton to 11 ton. Additional tolerance of 10% was also added to rear axle. In total, a vehicle with axle load of 12 ton was given especial permit. At the time of decision, a private consultant was studying the economic feasibility of increasing axle load limits. Effort was made to contact consultant through email, however no response was given. Hence this study assumed that no damage analysis was performed before the especial permit.

The second case is a special permit given to heavy vehicles with two axles (1.2 types). These vehicles are usually overloaded at rear axle. Following discussion with the Ministry of Transport, decision was made to evaluate such vehicles based on their gross vehicle weight instead of axle load limit. As a result, such type of vehicle was allowed to use the road with a 15 ton per axle load since it was within the legal limit of gross vehicle weight.

Three problems are observed regarding the special permit process. Firstly, under both the above cases, no specific time limit was given in the letter written from the Ministry of Transport. Nevertheless, they serve as legal limit in actual practice. These changes were considered as a special permit, than a law as they weren't approved by House of People's Representative of Ethiopia and were not published in Negarit Gazeta.

Secondly, the conversion of total vehicle weight to axle weights is performed based on experience. This procedure doesn't take into account the geometry of the vehicle, pattern of loading and geometry of the road. Currently there are several axle load calculator software that provide fair approximation of axle weight based on vehicle type, spacing of axles, load amount and loading geometry. Freight transporters can provide this information to ERA axle weight section as part of information for special permit.

The final point is related to fee for special permit. The existing practice is to lay the responsibility for any damage caused on the road on the transporter. Road damage analyses are not performed before special permits are granted. A transporter pays nothing unless immediate damage is observed. However, road damage is accumulated over time (fatigue failure) and the vehicles with special permit take significant life of pavement without causing immediate failure. Hence, the economic impact of special permit is not known and there is no cost recovery mechanism because special permit is free of charge.

## 4.6. Overload Management at Addis Ababa – Adama Expressway

### 4.6.1. Axle Load Limits

Weighing limits of AAAEW considers both axle load limits and gross vehicle weight limits. User manual for the Addis Ababa –Adama Toll Collection System (2014) specifies the limits per axle type as summarized in Table 4.4. The specified axle load limits are provided in more detail compared to the axle load limits specified by ERA. It looks logical since it takes not only the axle spacing and axle load but also number of tires.

Table 4.4 Axle Load Limits of AAAEW (CCCC, *Addis Ababa –Adama Toll Collection System*, 2014)

Type N <sup>o</sup>	Description	Maximum loading(Ton)
0	Steering axle	8
1	Single Axle single tire	8
2	Single Axle dual tire	10
3	Tandem axles single tire each	9
4	Tandem axles single or twin tires each side	13
5	Tandem axles twin tires each side	17
6	Tridem axles single tire each side	12
7	Tridem axles, two single tire and one twin tire	16
8	Tridem axles, one single tire and two twin tire	20
9	Tridem axles twin tire each side	24

A digital display provides the number of axles per vehicle, axle and gross vehicle weight in real time. Overloaded weights are highlighted in the display along with extra overload weight. The actual practice at Tulu Dimtu weighing station specifies gross vehicle weight limits as shown in Table 4.5 (CCCC, *Addis Ababa –Adama Toll Collection System*, 2014).

Table 4.5 Gross Vehicle Weight limits of AAAEW

Number of Axle	Maximum Gross vehicle weight limit
2	20ton
3	30ton
4	40ton
5	50ton
≥6	55ton

### 4.6.2. Overload Management

A digital weigh-in-motion weighing system is installed and utilised at the toll gates of the Addis Ababa-Adama Expressway. The low-speed weighing system was set up on the toll lane and used with the toll collection system together to weigh the passing vehicle and toll. The weighing and toll system consists of the weighing sensor, the weighing data collector, the vehicle separator, the axle recognizer, the detecting coil and so on. The major components of the weighing system are as shown in Figure 4.4.

The dynamic truck scale has static detecting and dynamic weighing two ways to work and provides valid measurement in speed range of 0-20 km/hr. A maximum of 30 ton can be weighed per single axle and the equipment requires calibration every 12 months.

Information that can be obtained from the weighing system include; axle weight, axle group weight, gross vehicle weight, number and configuration of axles, axle type, distance between axles, vehicle speed, date, etc. The system also saves data automatically and information can be accessed when required. Figure 4.4 illustrates components of the weighing system at the Addis Ababa - Adama Expressway.

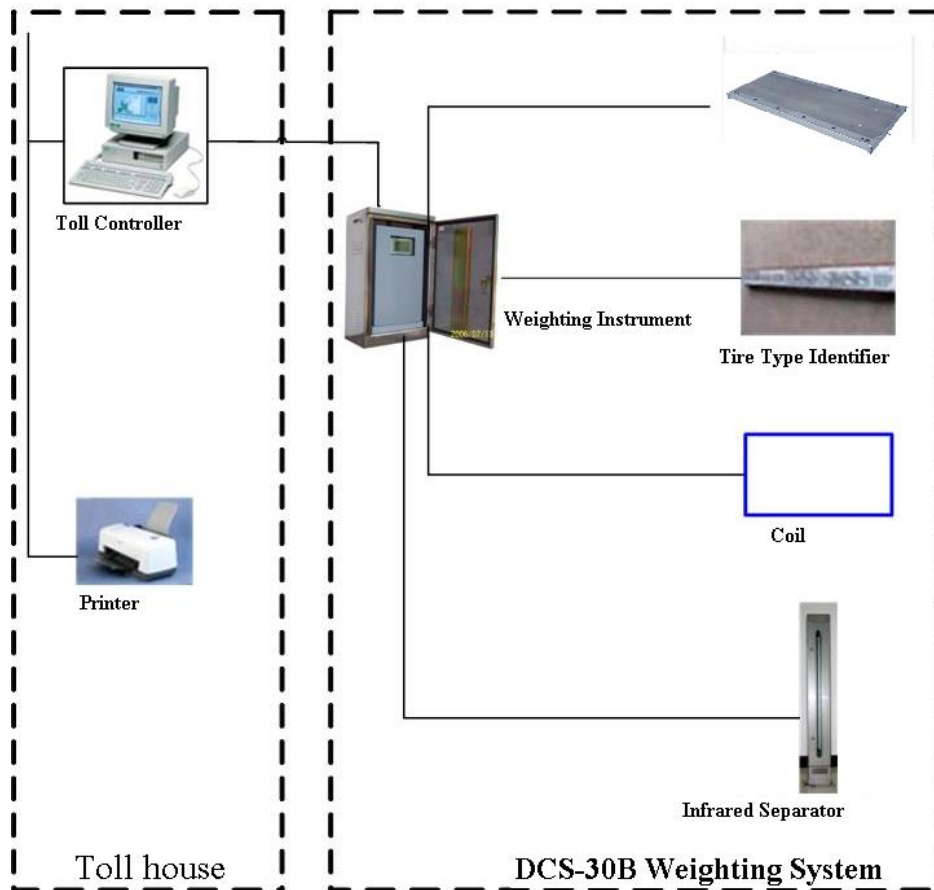


Figure 4.4 Components of Weighing System at AAAEW (ETRE, 2014)

The weight of individual axles and gross vehicle weight is also provided. Table 4.6 demonstrates sample of data representation in the weighing system.

Table 4.6 Sample Dynamic Weighing in Motion Data

Check ID	Axle Weight	Gross Vehicle weight	Nº of Axles	Limit Weight (Kg)	Speed (km/hr)	Time and date	Over Limit	Vehicle Type
40980	6380	14940	3	30000	8km/hr	10 55 09 12/31/2014	-	1.22
	4420							
	4140							

Vehicles are weighed using digital weighing scales which can automatically detect overloaded axles and trucks. Weighing lane is opened to a single vehicle at a time. This implies that other vehicles have to wait in queue till the weighing lane is open. The system provides vehicle type recognition equipment; vehicle type and axle number of the first vehicle in queue will be displayed on the computer. A supervisor has to confirm the data however undo options are also available.

The system interface display allows overload detection of overloaded trucks. The User Manual for the Addis Ababa – Adama Toll Collection System (2014) recommends stopping transaction of overloaded trucks and returning the vehicle. It also specifies that overloading could be ignored for some special reason. However, the Manual emphasise the need to inform the motorist of overloading and the penalty rules. Ignoring overloading should also be reported to and authorised by supervisor. However, the special reason for ignoring overloading and the amount penalties are not provided.

The overload management of the Addis Adama Expressway is much improved as compared with the Modjo Weighing station. The basic reason for this is related with weighing system involved. A digital weighing system of AAAEW allows for immediate detection of overloading. The measure taken on overloaded trucks is however only preventing overloaded trucks from using the Expressway. Overloaded trucks that are denied access at toll gates will turn around and continue their journey using the old Addis Adama road without offloading extra weight. This procedure protects AAAEW road link while it increases road damage on the alternative route.

As discussed previously, the Council of Ministers Regulation to amend the vehicle size and weight regulations, N<sup>o</sup> 11/1990 requires offloading extra weight and persecuting vehicle operators before continuing their journeys. Consequently, a traffic police or ERA weighing Station management officers could be assigned at toll gates to implement the regulation.

## 4.7. Overloading Statistics

### 4.7.1. Axle Load Data on Addis Ababa – Djibouti Road Corridor

The Awash and Modjo weighing stations are located along the Addis Ababa – Djibouti road corridor. Axle load data of the two weighing stations was analyzed based on ERA weighing stations management data. In the past five years, a total of 884,290 front and rear axles had been weighed at Awash Weighing stations. Out of these, 1-2% of front axles and 5-20% of rear axles were overloaded. On average, 70% of overloading on front axle was within one ton and 49% of overloading on rear axle was within two ton off limit. Similarly, during the same years, a total of 973,552 front and rear axles had been weighed at the Modjo station. Out of these, on average 1% of the front axles and 6% of rear axles were overloaded.

Average of five years (2009-14) data was plotted using standard chart with load measured on x-axis and % of all measured axles on y-axis. Figures 4.5 and 4.6 show the distribution curves for Awash and Modjo weighing stations respectively.

The resulting curves resemble normal distribution. Axle weights of the vehicles are random in its nature for various reasons. Since weight is a continuous data, normal distribution of weighing station data could be highly likely.

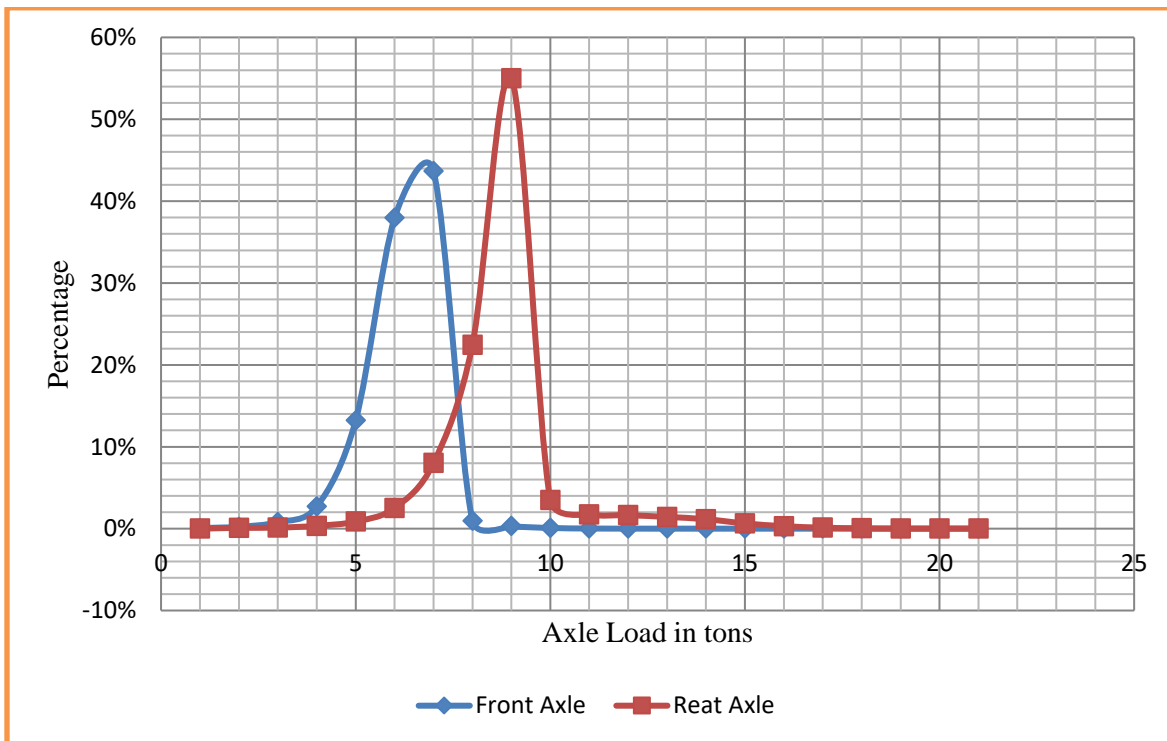


Figure 4.5 Five Years [2009-14] Average Axle Load Distribution of Awash Weighing Station

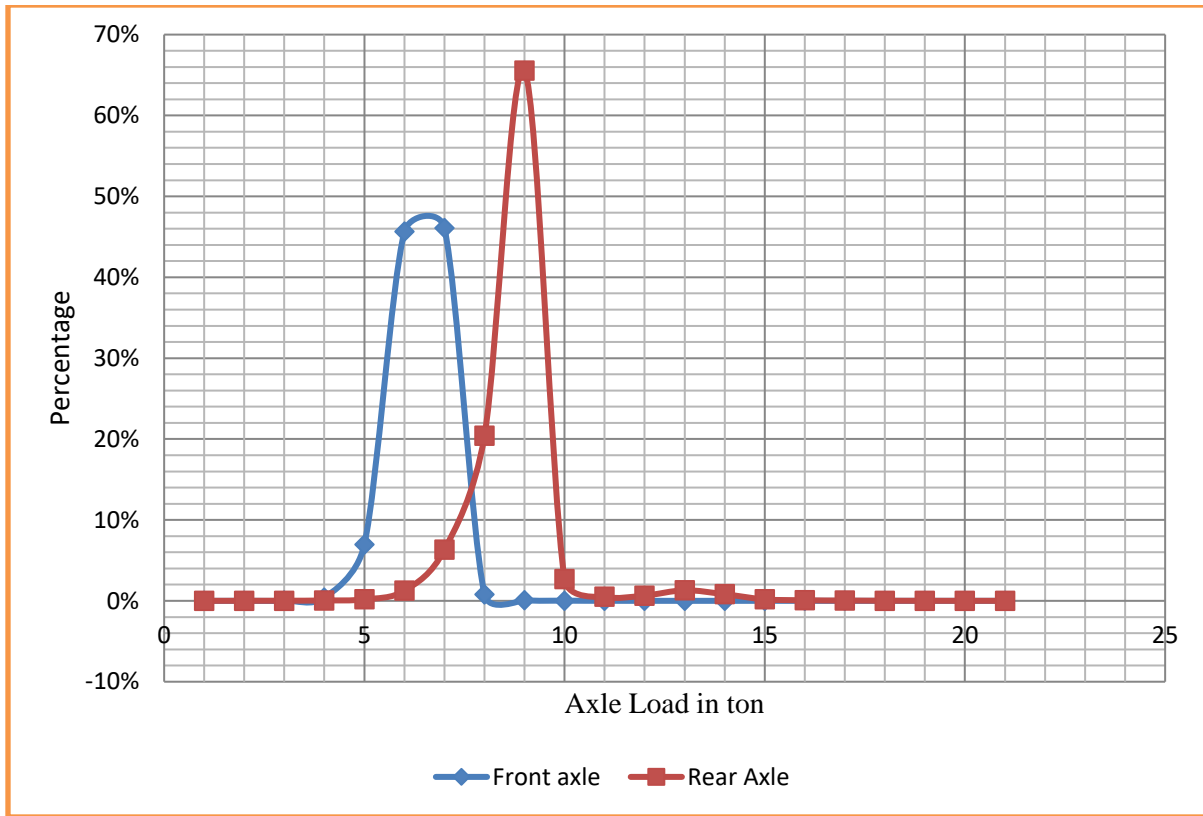


Figure 4.6 Five Years [2009-14] Average Axle Load Distribution of Modjo Weighing Station

Comparison of overload trend was also performed between Awash and Modjo weighing stations using the past five years [2009-14] data. As demonstrated in Figure 4.7, the trend of overloaded front and rear axles has a decreasing nature at Awash Weighing Station. On the other hand, the trend of overloading at Modjo Weighing Station increases and then decreases sequentially every year. Both Awash and Modjo weighing stations are on the same corridor, and hence the trend was expected to be similar. As the weighing machine is the same at both weighing stations, the most probable reason for the variation could be manual recording at weighing stations. This puts the reliability of secondary data of weighing stations under question.

Consequently, actual field survey was conducted at Modjo weighing station. The weighing station was selected due to its proximity to the study area (Addis Ababa – Adama Road link).

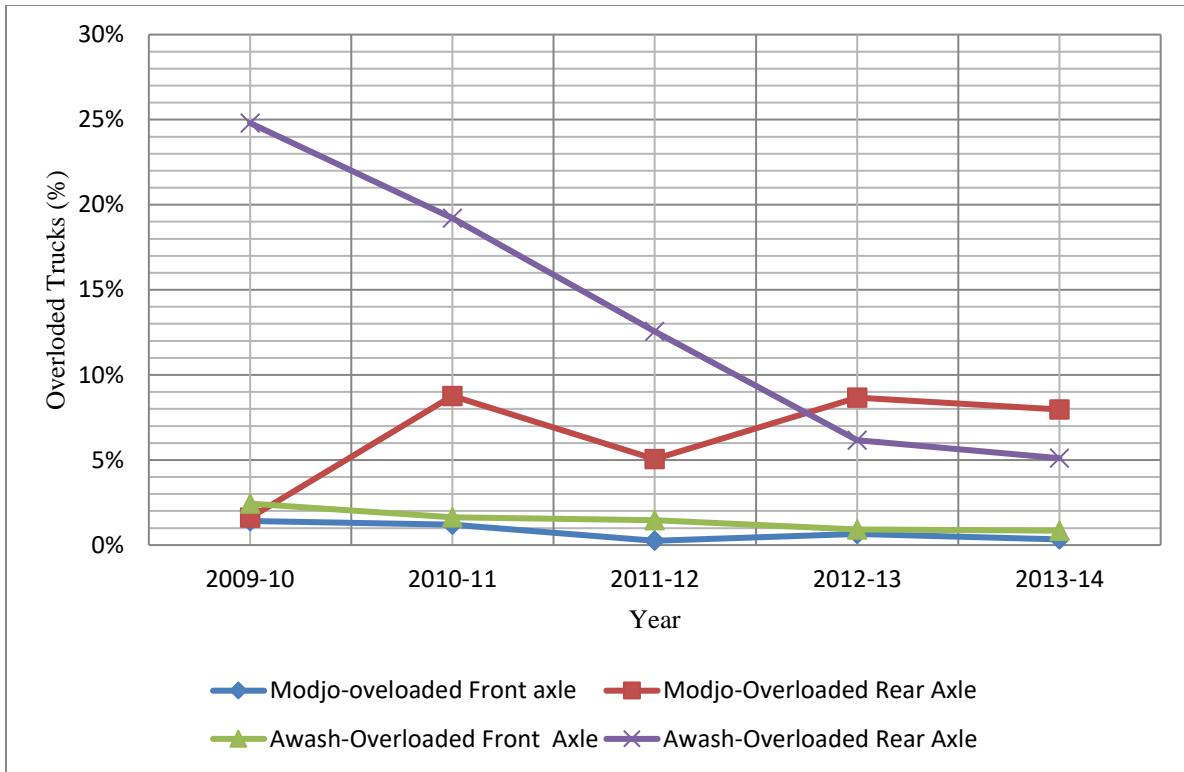


Figure 4.7 Overloaded Axles Trend at Awash and Modjo Weighing Stations

#### 4.7.2. Overload Cases

In order to analyse the economic impact of overloaded trucks, which is the base for determining overload fine structure, overloaded trucks were ideally allowed to use the road. In actual world not every axle is overloaded and neither the overloading rate is constant among vehicles or axles. In this study, five overload cases were considered, in addition to the base case (normal traffic). The cases allow assigning different charges depending on severity of overloading per axle.

Five overload cases were identified at interval of 10% overload per axle based on observation weighing stations data as described in section 3.3.1. The 10% interval was selected based on aggregate data collection formats used in Axle load management section of ERA. The percent of overloading per axle was used due to constant relative damage for front and rear axles relative to their legal limit as demonstrated in Table 4.7. This will simplify the analysis and cost distribution after economic impact is analysed. As demonstrated in Table 4.7, the 10% overloading on front or rear axle will have the same relative damage of 1.54.

Table 4.7 Comparison of Relative Damage of Front and Rear Axle Percentage Overloading

	Front Axle	Rear Axle
Legal limit	8ton	10ton
10%overloading	$8+10\%*8=8.8\text{ton}$	$10+10\%*10=11\text{ton}$
Relative damage of 10%overloading with respect to legal limit	$= \left(\frac{8.8}{8}\right)^{4.5} = 1.535561$	$= \left(\frac{11}{10}\right)^{4.5} = 1.535561$

Case 1 allows normal traffic and trucks overloaded up to 10% per axle to use the road without unloading extra weight. Case 2 allows trucks in Case 1 and trucks overloaded up to 20% per axle to use the road without unloading extra weight etc.

Prediction of traffic under each overload case was also performed. Under normal traffic of Case 0, no overloaded trucks were allowed to use the Expressway. Any overloading was immediately detected and overloaded trucks were forced to turn around prior to attending the toll gates. The annual AADT, proportion of vehicles, trucks factor and other parameters of Case 0 (normal traffic) was assumed to be the same as the one used in pavement design.

The AADT of trucks for overloaded cases was estimated using the proportion and overload pattern of overloaded trucks. Proportion of overloaded trucks and overloading pattern among vehicles was determined from Modjo Weighing Station.

From weighing stations observation, overloaded vehicles usually unload (adjust) extra weight to the nearest legal limit, to reduce cost of unloading. Accordingly, overloaded trucks beyond particular case were unloaded to the maximum allowed overload case understudy before using the road. The truck factor after unloading extra weight was taken as similar to truck factor of maximum overload case understudy. For example, overload Case 2 allows, normal trucks, trucks with 10% overloading per axle and trucks with 20% overloading per axle to use the road. If a vehicle is 30 % overloaded per axle, it has to unload extra weight to the maximum permitted overloading of 20% under Case 2. The equivalent axle load factors after unloading extra weight was also assumed to be similar to maximum permitted overload per axle, in this case the same as 20% overloaded trucks.

Extra weight from vehicles that overload beyond particular case understudy was assumed to be transported using extra vehicles that would generate additional traffic to the annual AADT which considered as generated traffic. These vehicles were predicted by estimating the number of vehicles required to transport extra weight. The generated traffic was assumed to have similar truck factor as normal traffic.

### 4.7.3. Overloading Pattern Used for the study

The proportion of overloaded trucks in vehicle category was determined from 2013 Modjo weighing station data. The year 2013 was preferred as it is the year immediately before the opening of AAAEW. In 2013, the only route between Addis Ababa and Adama was the old Addis Ababa - Adama Road. The traffic for AAAEW was also a diverted traffic from old Addis Ababa - Adama Road. Hence, the proportion of overloaded trucks on the old Addis Ababa - Adama Road was assumed to be representative to the road link under study.

One of the challenges regarding axle load management is related with vehicles that change route to avoid the Modjo Weighing Station. According to Modjo Weighing Station 2013 data, up to 10% of all heavy vehicles expected to be weighed, would pass the Station without stopping or changed their routes to internal local roads of Modjo. Consequently, overloaded trucks correction was made for vehicles that avoid weighing stations. Based on analysis of the 2013 Modjo Weighing Station data, 33% of all vehicles weighed were overloaded. In respect of vehicle category, 28% of heavy trucks and 45% of truck and trailers were overloaded.

However, the 2013 axle load data lacks detail and precision to determine overload distribution among axles of individual overloaded trucks due to manual recording instead of using machine. Accordingly, field axle load survey was conducted in 2014 to determine the overload pattern among axles. Axle load configuration and data collection format can be seen in Appendix A.

Based on site observation, the vast majority of heavy trucks were with three (3) axles configuration of 1.22 and truck and trailer were mostly with 6 axles with axle configuration of 1.22+2.22 or 1.22-2.22.

The overloading pattern was different among vehicles axles. Most vehicles were overloaded on some of their rear axles only. Front axle overloading was within single (1) ton off specified limit of eight (8) ton while rear axle overloading went up to 60%. Consequently, front axle overloading was considered only within 10% difference as described in overloaded cases and rear axle overloading however was taken based on the actual overload pattern (overload pattern/case).

The data collected during field survey was analysed to determine the pattern of overloading on front and rear axles. Then, the overload spectra of both heavy trucks and truck and trailers were estimated taking weighted average of front and rear axle per vehicle. Figure 4.8 demonstrates the distribution among front axle, rear axle and heavy trucks. The Figure presents the axle overload load distribution at 10% interval. All axle loads in between were rounded up to the higher overloading cases for convenience of equivalent axle load factor analysis.

The three lines represent overload pattern on front axle, rear axle and weighted average per vehicle was used in economic analysis. For example, 52% of overloaded heavy vehicles were overloaded only 10% above the legal limit per rear axle, 24% of overloaded heavy trucks were overloaded between 20% above the legal limit per rear axle, etc.

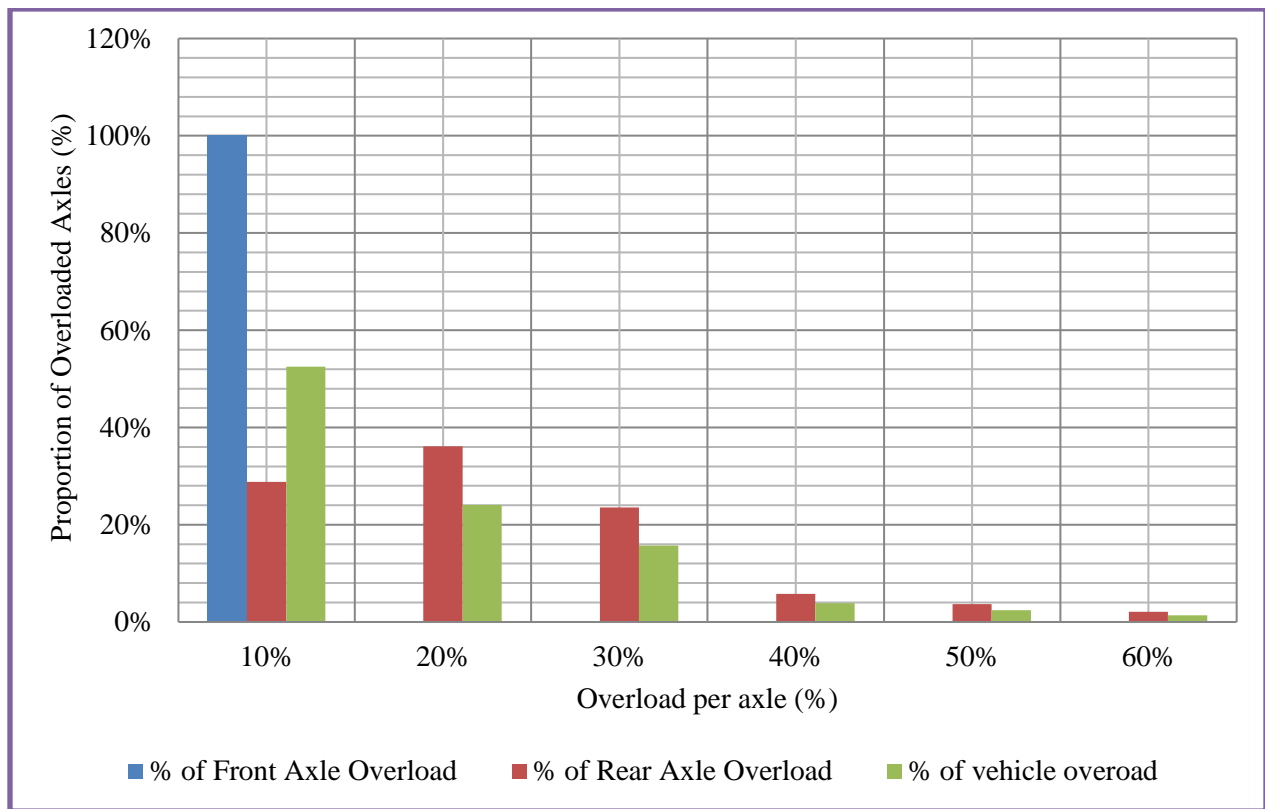


Figure 4.8 Overload Patterns of Heavy Vehicles

- **Truck and trailer [6 axle]**

Proportion of truck and trailers with number of axles less than six was only 7% of all truck and trailers. Hence, the truck and trailer vehicle class was considered as a six axle vehicles for minimizing the number of vehicle categories in HDM 4 analysis. Accordingly, analysis of distribution of overloaded axle was also performed. Figure 4.9 demonstrates the distribution among front axle, rear axle and vehicles which were used for economic analysis. For example, 29% of overloaded truck and trailers were overloaded only to 10% above the legal limit, 43% of the overloaded truck and trailers were 20% above the legal limit etc.

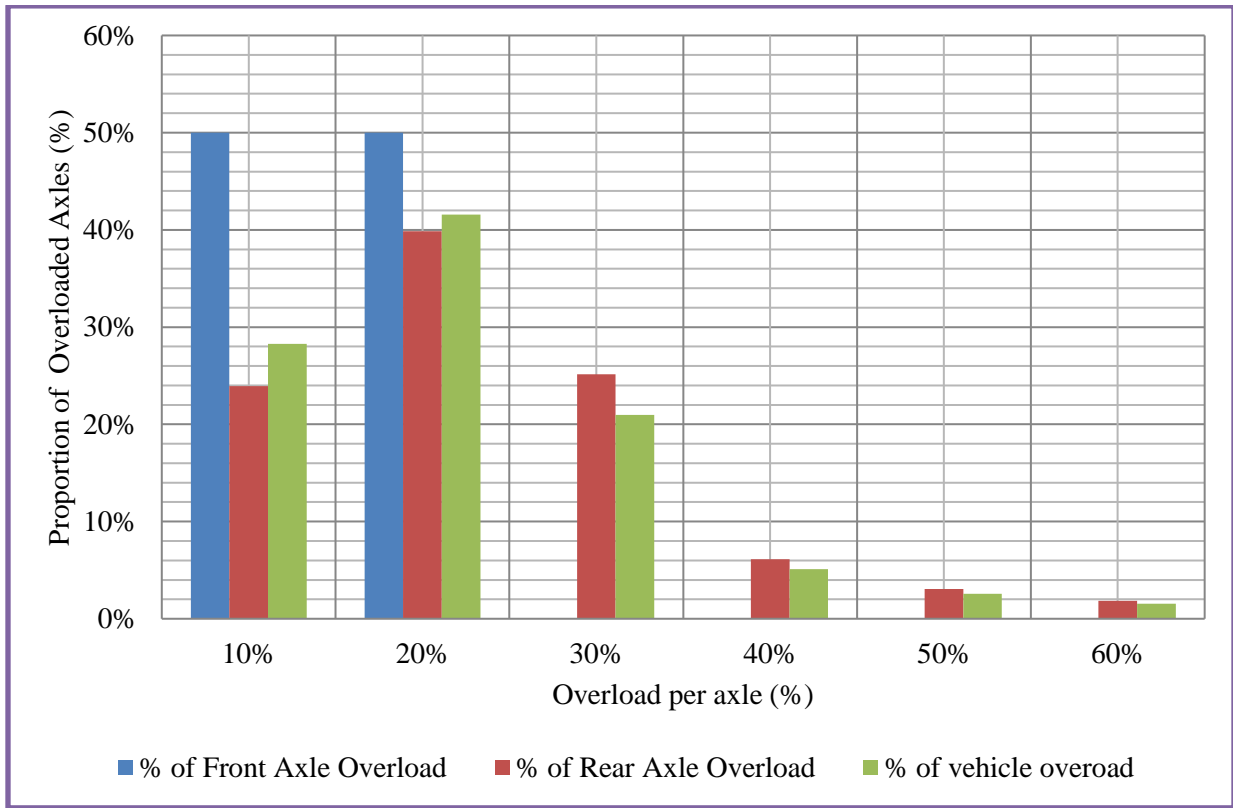


Figure 4.9 Overload Patterns of Truck and Trailer

## 5. CASE STUDY; ADDIS ABABA – ADAMA EXPRESSWAY

### 5.1. Background

The road link considered for overload analysis was the new Addis Ababa-Adama Expressway. The expressway is 78.3 km long and it is a new link road between Addis Ababa and Adama. The China Communications Construction Company (CCCC) inked a deal with the Ethiopian Roads Authority (ERA) in June 2009 and commenced construction in April 2010. The Expressway was designed and built by CCCC and supervised by Beijing Expressway Supervision (BES). The road was finalized and inaugurated on May 5, 2014 and was officially opened to traffic on September 14, 2014.

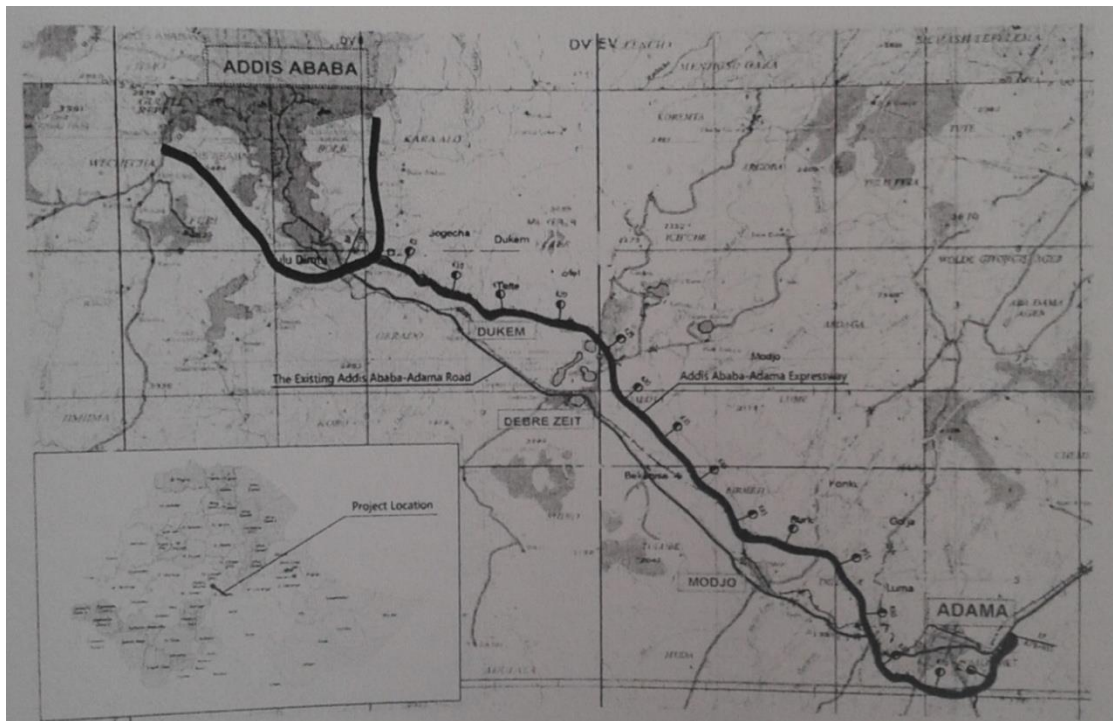


Figure 5.1 Alignment Map of Addis Adama Expressway (CCCC, *As built pavement report*, 2014)

The Expressway is managed by the Ethiopian Toll Road Enterprise (ETRE), a state-owned Enterprise. The Enterprise is accountable to the Ministry of Transport and its operation is closely supervised by a board of directors. The ETRE has three directorates within it that are responsible for: toll management, toll operation and engineering, and human resources. This section covers data related to road link characteristics, vehicle fleet and maintenance work standards which form the base to obtain optimized maintenance standards using HDM-4 lifecycle programme analysis. It also presents estimated NPV/C of road sections under overload cases and determination of rationalized overload fine.

## 5.2. HDM-4 Inputs

HDM-4 requires quality and reliable data inputs. In this study maximum effort was made to collect actual data of road links and study sections based on HDM-4 requirements. Most data were obtained through analysis of pavement design, soil investigation, and geometric design reports of AAAEW. Additional data related to maintenance work standards and cost was obtained from ERA and AACRA Offices. Overload pattern used for the study was obtained through data analysis and field survey at the Modjo Weighing Station. Basic data used in HDM-4 are presented and summary of data inputs is given in Section 5.2.13.

### 5.2.1. Road Sections Considered for Analysis

The Expressway, which starts at Tulu Dimtu, 2.8 km from Kality towards Adama, links Dukem, Bishoftu (Debre Zeit) and Modjo, before reaching Adama. Tollgates are located at Addis Ababa, Adama and at six interchanges. The total road length is 78.3 km, with dual six lanes of expressway standard, with design speed between 80 km/hr and 120 km/hr with total width of 31m.

As demonstrated in Figure 5.2, the entire Expressway was divided into five relatively homogeneous sections. These are:

- Section 1: Addis Ababa – North Debre Zeit [AA-DZ] [K2+800 - K17+000];
- Section 2: North Debre Zeit – Modjo [DZ-MO] [K17+000 - K52+200]
- Section 3: Modjo – Adama West [MO-AW] [K52+200 - K60+500]
- Section 4: Adama West – Asela Road [AW-AR] [K60+500 - K71+700]
- Section 5: Asela Road – Adama [AR-AD] [K71+700 - K78+000]

The study sections were divided as such considering similarity of traffic, topography and Subgrade soil characteristics and they were utilised in the analysis of the Expressway in respect of the sections using the HDM-4 Programme Analysis. Data required for each road section was determined with average attributes of road geometry, pavement type, environment, road condition, etc.

The traffic matrix and growth rate of each road section was different in opposite directions. This requires separate HDM-4 analysis to be performed for Addis Ababa- Adama and Adama to Addis Ababa directions. The vehicle Composition also varies for each overload case (Case 0 to Case 5). Accordingly, twelve (12) separate road links were defined with the code AAA-EW-1 to AAA-EW -12. The first six (6) links included the above five road sections from Addis Ababa to Adama, downhill direction, each representing one overload case (Case 0 –Case 5). The remaining six (6) road links included similar five road section, from Adama to Addis Ababa uphill, direction. Most road attributes are the same for all road links except differences in traffic and direction of travel.

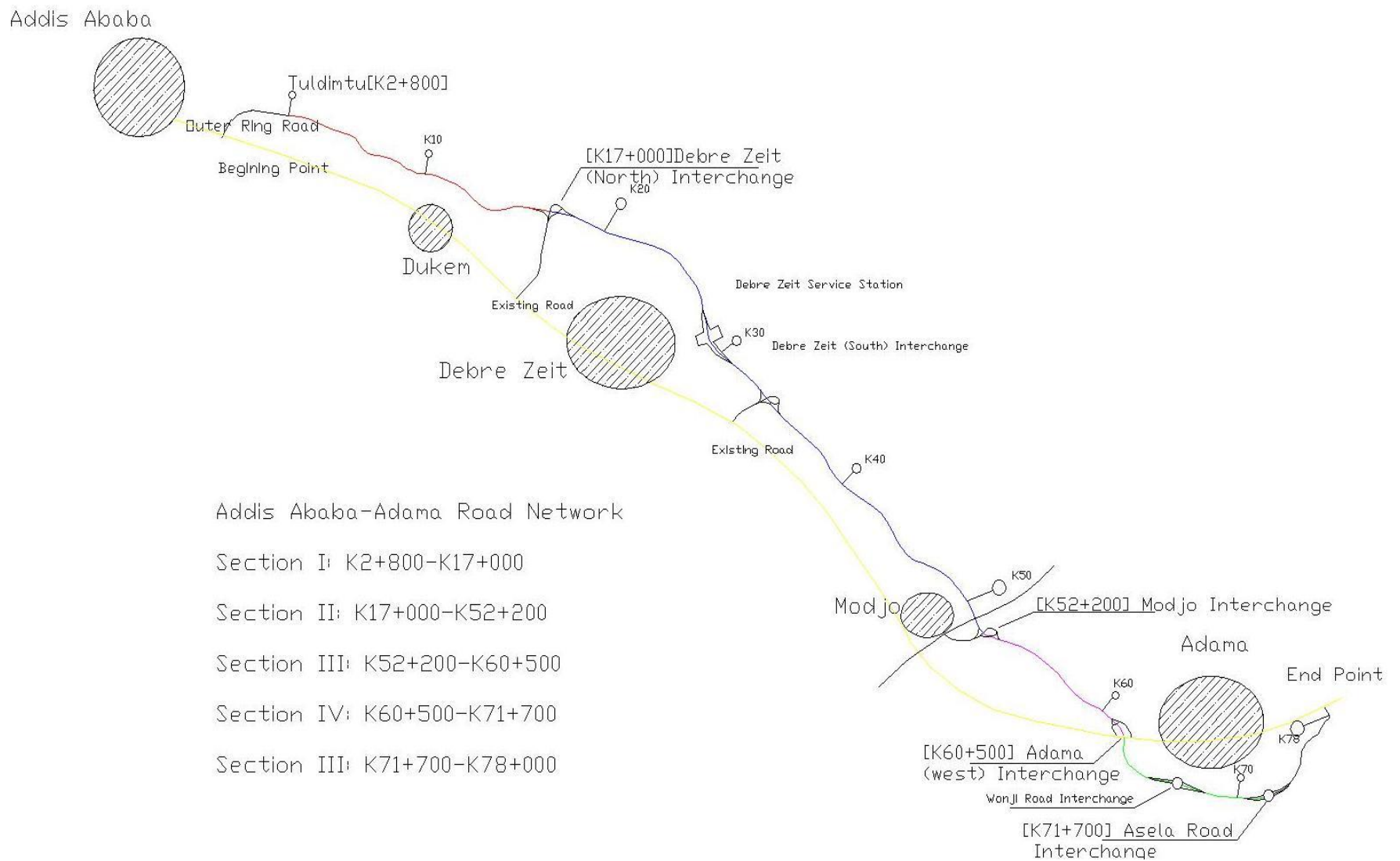


Figure 5.2 AAAEW Road Link and Study Sections (No Scale)

### 5.2.2. Topography

Altitude of each road sections is also required as one input in HDM-4 Programme Analysis. Consequently, the vertical profile of the study road link was prepared based on geometric report of the Addis Ababa – Adama Expressway (2011). Figure 5.3 demonstrates the vertical alignment of the Addis Ababa –Adama Road Link. The x-axis gives the chain-age of the alignment of the centre of the road while the corresponding elevation above mean sea level is indicated on the y axis.

The altitude of individual sections varies across the road. For HDM-4 input, the altitude of each section was determined from the average of the altitude of vertical points of intersection. There is a large variation in elevation of vertical point of intersections between K2+100 - K16+000. Road Section K0 - K17 & K57 - K79 is generally rolling type with maximum gradient of 5% (CCCC, *Geometric Design Report*, 2011). The remaining road section between K17 and K57 is flat with maximum gradient of 3.7% (CCCC, *Geometric Design Report*, 2011). The vertical separators in Figure 5.3 are placed to indicate the span of study road sections.

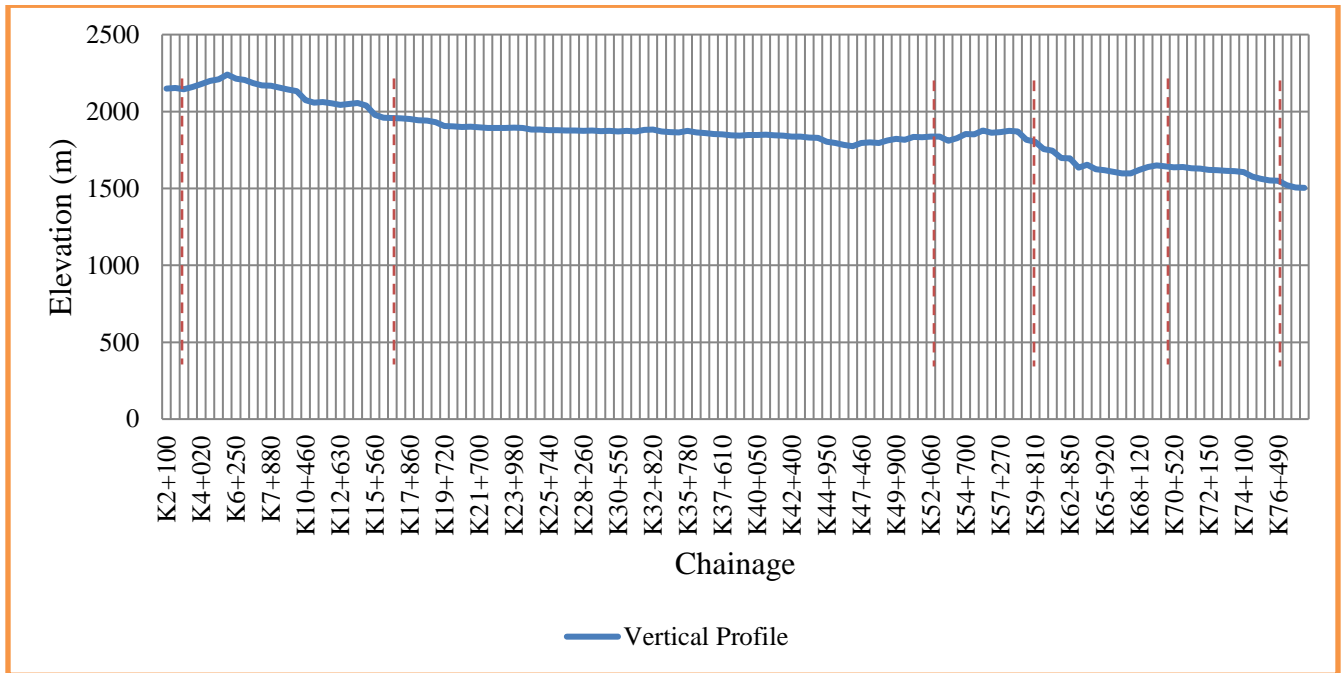


Figure 5.3 Vertical Alignment of AAAEW

### 5.2.3. Climate

The climate of a road area has a significant impact on the rate at which it deteriorates (Morosiuk et al, 2004). Temperature, rainfall and winter condition of the area were the main climate conditions considered in pavement design. This section describes the principal climatic data that are used in the road deterioration model of HDM-4.

#### 5.2.3.1. Temperature

Based on metrological data, the temperature ranges between 9°C and 30.66°C (CCCC, *As built pavement report*, 2014). Figure 5.4 demonstrates the monthly highest, lowest and mean temperature of project area. The mean annual temperature of Addis Ababa ranges from 10.68°C to 23.48°C, and the temperature of Modjo town range from 12.08°C to 23.48°C. In the case of Adama City, it ranges from 14.14°C to 28.01°C.

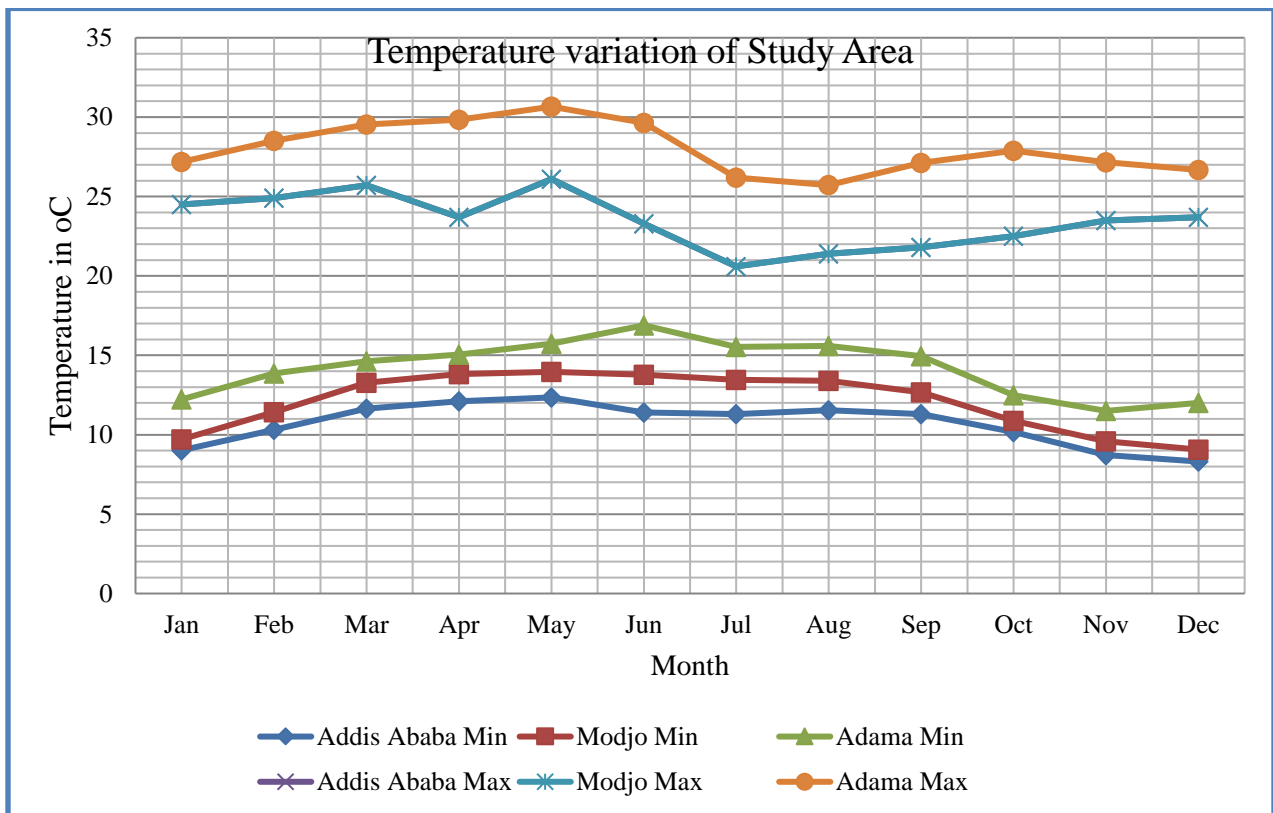


Figure 5.4 Temperature variations along Project Route

The project area has gentle and less temperature variations. Hence, low temperature during winter time is not a problem but rather an advantage to the pavement structural design (CCCC, *As built pavement report*, 2014).

### 5.2.3.2. Rainfall

The rainfall data of project area, which was obtained from the Central Bureau of Statistics of Ethiopia, is shown in Figure 5.5. Accordingly, the rainfall in the project area ranges between 876.4mm and 1039.0mm. The rainy season is mainly between June and September and accounts for 71.6% of the annual rainfall. The remaining season is more of dry as evaporation is higher than the rainfall.

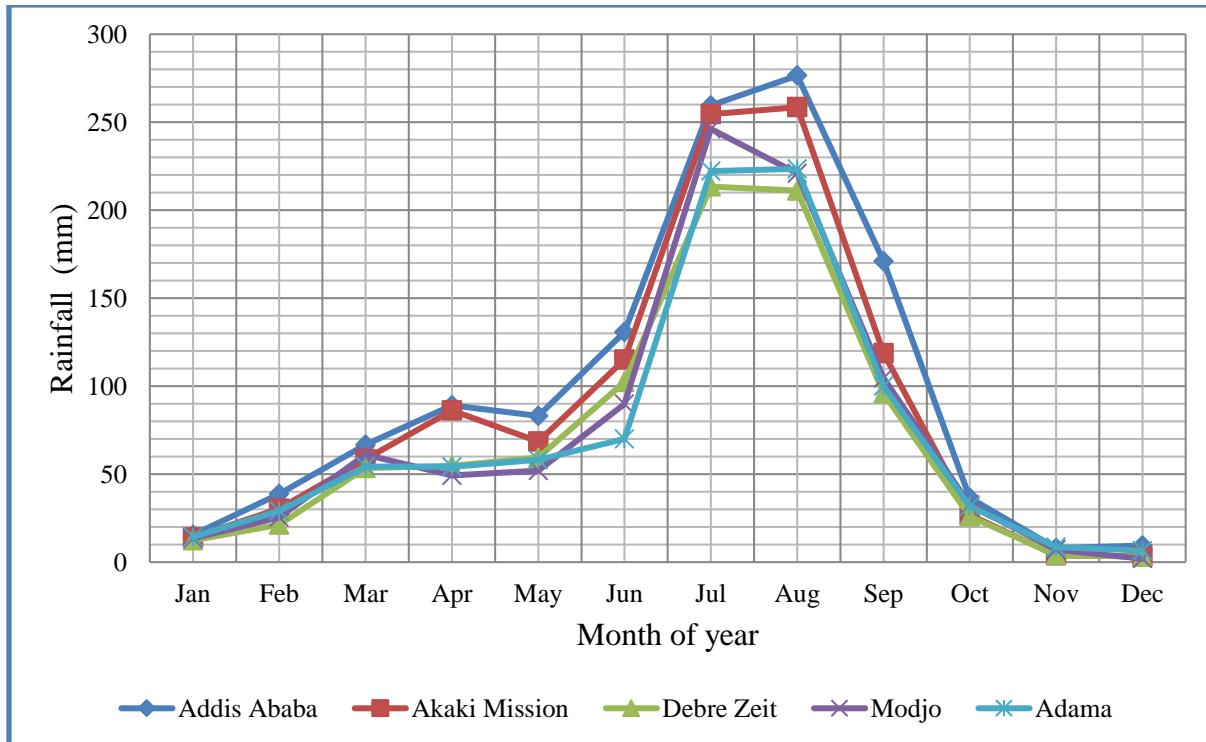


Figure 5.5 Mean rainfall of project area (CCCC, *As built pavement report*, 2014)

In conclusion, the temperature and rainfall condition in the project area is different from that of Chinese region with similar rainfall (CCCC, *As built pavement report*, 2014). From pavement design point of view, the climate of the project area is considered positive compared to the China case. Hence, utilising the Chinese specification was justified accordingly.

In HDM-4, the environment is classified under five moisture and five temperature classifications. The climatic zone of each section was identified based on the mean temperature, mean rainfall amount and configuration of HDM-4. Accordingly, the climate zone type of all the road sections were classified as sub-humid tropical.

#### 5.2.4. Subgrade Soil Strength

Subgrade CBR is another important input for HDM-4 Programme Analysis. The major unfavourable geology of the project area was black cotton soil. About two-third of the entire road link (K0 - K60 km), pass through sedimentary black cotton soil with height in range of 1 - 3m. The majority of the black cotton soil has a CBR 1-3% in range and plasticity Index (PI) is greater than 20 and undergoes great volume change (CCCC, *As built pavement report*, 2014).

The volume change would result in Subgrade instability and eventual failure of the pavement surface. Consequently treatment, replacement or improvement of existing Subgrade was performed in order to obtain stable and high strength Subgrade. According to Ethiopian experience and regular practice, a capping layer of 30 cm thickness and  $E_0 = 60\text{Mpa}$  was used for upper road bed enhancement. Subgrade treatment scheme was also implemented at connection section of fill and cut (CCCC, *As built pavement report*, 2014).

Sections between K60 to the end have variable CBR values ranging from 3% - 51% as shown in Figure 5.6. Design Subgrade CBR=6% was assumed for the entire road link during design of the pavement.

However, the assumption works for section from start to K52+200. This assumption provides relatively thicker pavement for sections between K52+200 and endpoint (CCCC, *As built pavement report*, 2014).

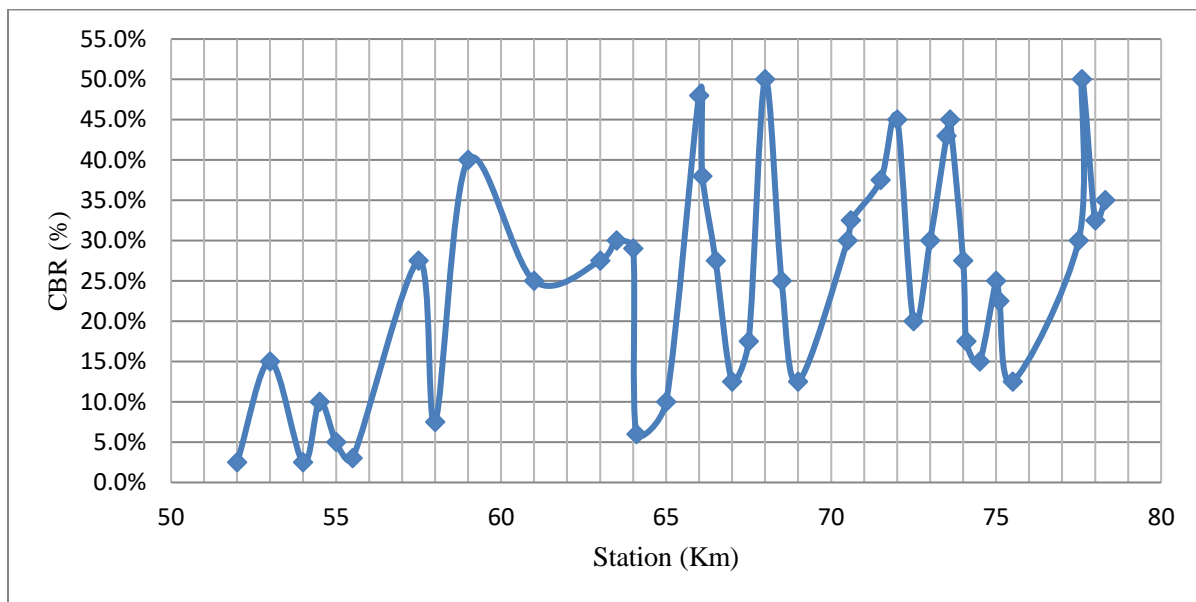


Figure 5.6 Subgrade Soil CBR along stations (First Highway Consultants Limited, 2012)

In this study Subgrade CBR of 6% was used from K2+800-K52+100 (AA-DZ and DZ-MO). For the remaining section (K52+10-end) the Subgrade CBR which is exceeded by 90th percentile was determined as per ERA Pavement Design Manual I (2002) recommendation and based on soil investigation report (2014). Detail of procedure and selected CBR values are demonstrated in Appendix B.

### 5.2.5. Traffic

Traffic is one of the key variables in HDM-4 road deterioration modelling. According to numerical models established for prediction of AAAEW traffic, vehicles were classified in to three classes, which are listed in Table 5.1

Table 5.1 Different vehicle Classes of AAAEW (CCCC, *As built pavement report*, 2014)

User Class	Vehicle Category
UC1: Cars	Car, 4WD
UC2: Buses	Small Bus, Large Bus
UC3: Trucks	Small Truck, Medium Truck, Heavy Truck, Truck and Trailer/ Articulated

UC: User Class

Traffic Capacity forecast for the Addis Ababa - Adama Expressway was performed by **Scott Wilson Kirkpatrick & Co. Ltd (SWK)** . The traffic forecast made by SWK was later modified during pavement design. Points considered for traffic adjustment include

- **Tolling:** Traffic analysis by SWK was made without the consideration of tolling. Road user analysis was performed to include the correction.
- **Interchanges:** the interchanges of the project are six in total reducing three out of nine originally assumed during traffic volume forecast.

Accordingly, prediction was made under tolling regime for the main road and Six (6) interchanges at: North Debre Zeit (Dukem), South Debre Zeit, East Modjo, West Adama, Wonji Road and Asela Road were finally considered. The forecasted traffic volume used for design of pavement are larger and conservative than predicted by SWK and hence the designed pavement thickness is a bit thicker (CCCC, *As built pavement report*, 2014).

The traffic model by SWK predicted few buses to use the expressway as most would need to use the existing road that passes through the main towns and villages, for peaking up and dropping off passengers. Accordingly, Busses (User Class 2 or US2) were not included in the summary for flow of the expressway (CCCC, *As built pavement report*, 2014).

In contrary to this assumption, buses were using the Expressway during the time of study. The feasibility study made by Abdisa (2011) also included Buses into traffic analysis. In this study, buses were not considered in the traffic analysis as they were not included in analysis of design life of the pavement.

The entire length of the main road was later divided into five design sections based on similarity in traffic volume. The road sections considered are the same as road sections considered in this study and detail of assumptions and traffic considered for interchange is discussed in Built Pavement Report (2014). Table 5.2 shows the traffic data used for the design of pavement of five sections of the main road.

Table 5.2 Total Adjusted AADT used for Main road pavement Design (CCCC, *As built pavement report*, 2014)

Road Section	User Class	From Addis Ababa towards Adama						From Adama to Addis Ababa					
		2010		2020		2030		2010		2020		2030	
Addis Ababa - Debre Zeit	UC1	185	873	4724	1999	8283	3376	2407	1126	4583	1965	8031	3248
	UC3	8	985		2725		4907		1281		2618		4783
Debre Zeit - Modjo	UC1	195	809	4456	1705	7915	2845	2197	814	5390	1864	9196	2975
	UC3	5	1146		2751		5070		1383		3526		6221
Modjo - Adama West	UC1	165	575	3623	1274	5539	1821	1876	784	3679	1399	5824	2080
	UC3		1081		2349		3718		1092		2280		3744
Adama West – Asela Road	UC1	199	765	3828	1333	5857	1906	1883	104	3602	1379	5497	1976
	UC3		1226		2495		3951		1779		2223		3521
Asela Road - Adama	UC1	651	144	1284	251	1996	360	570	64	1147	114	1797	161
	UC3		507		1033		1636		506		1033		1636

The traffic growth rate was not explicitly indicated in the as built design document. However it was back calculated from the given traffic for 2010, 2020 and 2030 and using equation 5.1 from ERA (2002) Pavement Design Manual I.

$$AADT_1 = AADT_0 * (1 + i)^x \dots\dots\dots 5.1 \text{ (ERA, 2002)}$$

Where AADT<sub>1</sub>: Annual Average Daily Traffic at the beginning of design period (2014)

AADT<sub>0</sub>: Annual Average Daily Traffic at time of traffic count (2010)

x: number of years between traffic count and opening of the road for traffic.

i: the growth rate

Table 5.3 presents back calculated the growth rates of different sections used for HDM-4 analysis.

Table 5.3 Traffic Growth Rates of Five Study Road Sections in Two Directions

User Class	Road Section	Addis Ababa towards Adama		Adama towards Addis Ababa	
		2010-20	2020-30	2010-20	2020-30
UC1	Addis Ababa - Debre Zeit	8.6%	5.4%	5.7%	5.2%
UC3		10.7%	6.1%	7.4%	6.2%
UC1	Debre Zeit – Modjo	7.7%	5.3%	8.6%	4.8%
UC3		9.2%	6.3%	9.8%	5.8%
UC1	Modjo - Adama West	8.3%	3.6%	6.0%	4.0%
UC3		8.1%	4.7%	7.6%	5.1%
UC1	Adama West – Asela	5.7%	3.6%	29.5%	3.7%
UC3		7.4%	4.7%	2.3%	4.7%
UC1	Asela - End Point [Adama]	5.7%	3.7%	5.9%	3.5%
UC3		7.4%	4.7%	7.4%	4.7%

### 5.2.6. Overloading Cases Considered for Analysis

Overloaded Vehicles were ideally allowed to use the road in order to analyse their impact on road pavement. Overload pattern of the study area was also predicted based on data analysis from Modjo Weighing Station. Five overloading cases and a reference Case 0 (normal traffic) were considered for overload fine analysis as discussed in Section 3.3.1. The overload pattern under each case for each vehicle category was also assumed to be constant for all road sections. Separate vehicle types were created for each overload case considering the variation in truck factor and AADT under each case.

Different rates of overloading were considered separately in order to lay overload fine based on severity of overloading. The percentage of overloading approach was also preferred due to constant relative damage it provides regardless of being front or rear axle. This served as base for fair distribution of road damage cost among overloaded axles in spite of vehicle type.

### 5.2.7. Traffic for Overloading Cases

Traffic for Case 0 was assumed to be the same as the original traffic used in pavement design. For Case 0, overloaded trucks were forced trucks to turn around and use the old Addis Ababa - Adama Road. The pavement is therefore expected to perform with expected maintenance programme.

Traffic forecast was also made for five overloading cases of all road sections. From weighing station observation, Cars, Four Wheel Drives, Small Trucks and Medium Trucks were passing without being weighed. These vehicle types were not to weighed because they are less susceptible to overloading. Hence, the AADT of these vehicles was taken the same for all overload cases.

The AADT of overloaded trucks i.e. heavy trucks & truck and trailers, in each overloading case was estimated by classifying vehicles into four parts:

- **Normal Traffic:** involves normal trucks that obey the legal axle load limits. Their proportion was found by deducting the proportion of overloaded trucks from the total traffic. Proportion of overloaded trucks was determined from Modjo Weighing Station data.
- **Overloaded Trucks 1:** Include trucks that overload to the particular case under consideration. Overloaded trucks traffic under particular overloading case was determined from the proportion of trucks that fall within that particular case.
- **Overloaded Trucks 2:** Trucks that overload beyond the particular case under consideration were assumed to unload to the nearest overload case. From weighing stations observation, overloaded vehicles usually unload to the nearest legal limit; this could be to reduce cost of unloading extra weight. For example if we permit 20% overloading per axle, overloaded vehicles beyond 20% usually unload to the nearest permitted limit of 20% overloading per axle.

- **Generated Trucks:** represent traffic that did not exist in absence of overloading cases. Overloaded trucks beyond particular overloading case under consideration have to unload to the nearest overload case under consideration. The extra weight unloaded from overloaded trucks was assumed to be transported using extra vehicle. Extra weight from overloaded trucks above particular overloading case was estimated. Medium trucks with average capacity of 3 ton per vehicle were assumed to transport extra weight from Case 1 (10% overloaded trucks). Heavy Trucks of capacity 20 ton were also assumed to transport extra weight for the remaining cases. The additional traffic generated due to overloading was then predicted by estimating the number of trucks that would be required to transport the extra weight.

The equivalent axle load factor of generated traffic was assumed to be the same as normal trucks. After unloading, Truck 2 was assumed to have the same equivalent axle load factor as overloaded Truck 1.

Based on the above assumptions, traffic for each overload case was predicted and was used in HDM-4 programme analysis. The proportion of overloaded trucks was determined from axle load data of Modjo weighing station. The growth factors in Table 5.3 were assumed to remain the same for all overload cases. The estimated traffic for each overloading case and for each road section of Addis Ababa – Adama road link is presented in Appendix D1.

### 5.2.8. Equivalent single Axle Load Factor

Analysing the effect of traffic on pavement deterioration requires analysing the design Equivalent Single Axle Load factor. The equivalent standard axle load factor (ESALF) is defined as the number of applications of a standard 80KN dual-wheel single axle load that would cause the same amount of damage to a road as a one application of the axle being considered.

The impact of axle load was assessed based on this load equivalency factor discussed in Section 2.6. According to the Ethiopian Pavement Design Manual, the standard axle load for pavement design is 80KN and damage exponent is 4.5. Chinese Specification and procedures were followed in design and construction of pavement for AAAEW. According to Chinese specification (BZZ-100), the standard axle for pavement design is 100KN with power factor of 4.35 as shown in Equation 5.2.

$$LEF = \left( \frac{\text{Axle Load (kg)}}{10200\text{kg}} \right)^{4.35} \dots\dots\dots 5.2 \text{ (CCCC, As built pavement report, 2014)}$$

Accordingly conversion factor (K) between Ethiopian LEF and Chinese LEF was established as presented in Equation 5.3.

$$K = \frac{\text{LEF of Ethiopia}}{\text{LEF of Chinese}} = 0.683605 * (\text{Axle Load in kg})^{0.15} \dots 5.3 \text{ (CCCC, As built pavement report, 2014)}$$

Traffic flow proportion and weighted ESAL factor of design traffic was obtained from study by SWK during their traffic survey deployment on two cities of Kality and Modjo. Table 5.4 and Table 5.5 provide the ESALF used for the design analysis of the main road pavement (CCCC, *As built pavement report*, 2014).

Table 5.4 Addis Ababa Ring Road- Debre Zeit LEF (Based on Kality Survey)

User Class	Vehicle Type	Vehicle Proportion (%)	ESAL Factor by Vehicle Type		Weighted ESAL Factor by User Class	
			Ethiopian Standard	Chinese standard	Ethiopian Standard	Chinese standard
UC1	Car	50.1	0.001	0.0000	0.005	0.0022
	4WD	49.9	0.01	0.0044		
UC3	Small Truck	35.4	0.14	0.0566	6.56	2.3021
	Medium Truck	8.8	5.72	2.0445		
	Heavy Truck	18.1	9.34	3.2843s		
	Truck and Trailer	37.7	11.45	3.9990		

Table 5.5 Debre Zeit – Adama Traffic Composition (Based on Modjo Survey)

User Class	Vehicle Type	Vehicle Proportion (%)	ESAL Factor by Vehicle Type		Weighted ESAL Factor by User Class	
			Ethiopian Standard	Chinese standard	Ethiopian Standard	Chinese standard
UC1	Car	41.20	0.001	0.0005	0.006	0.0028
	4WD	58.80	0.01	0.0044		
UC3	Small Truck	35.90	0.14	0.0566	6.88	2.4094
	Medium Truck	5.50	5.72	2.0445		
	Heavy Truck	9.90	9.34	3.2843		
	Truck and Trailer	48.80	11.45	3.9990		

HDM-4 allows for the calculation of value of equivalent single axle load factor for each vehicle from axle load information. User can also specify equivalent axle load factors of each vehicle. In this study, the ESAL factor of normal traffic was taken as presented in Table 5.4 and Table 5.5.

Regarding the ESAL factor of overloaded trucks, only vehicles with gross vehicle weight greater than 7.5 ton were weighed at Modjo Weighing Station. As resulted, only the truck factors of heavy trucks and truck & trailers were varied between different overload cases. The following two assumptions were made based on observation of majority of trucks at Modjo Weighing Station.

- Heavy Vehicles; the vast majority of overloaded heavy trucks (almost 100%) were with three (3) axles per vehicle assumed axle load configuration of 1.22 (single front axle with two wheels and 2 rear axles with 4 wheels each)
- Truck and trailer, semitrailer; Majority of overloaded truck and trailers (more than 90%) were with six (6) axles per vehicle, assumed axle Configuration 1.22+2.22 or 1.22-222 (single front axle with two wheels and 5 rear axles with 4 wheels each)

With the above two assumptions, ESAL factor of overloaded heavy vehicles and truck and trailers were computed as per ERA Pavement Design Manual I (2002) recommendation as shown in equation 5.4.

$$ESALf = \sum_{i=1}^{i=k} \left( \frac{L_i}{L_{st}} \right)^{4.5} \dots\dots\dots 5.4$$

ESALF = Equivalent Standard Axle Load Factor

$L_i$  = Axle Load for  $i^{th}$  Axle of Vehicle Type x

$L_{st}$  = Standard Axle load taken as 80KN (8.16 ton)

Finally, the traffic composition and ESAL factor of vehicles considered in each overload case was determined. A summary of the type of vehicles considered for each overload case along with ESAL factor and gross vehicle weight is given in Appendix D2.

### 5.2.9. Vehicle Fleet Characteristics

HDM-4 estimates the benefits to society in terms of reduced costs to road users; therefore, economic road user costs are characterized for a given country as a function of the vehicle fleet unit costs, utilization and characteristics, and road characteristics.

A road user costs sensitivity study has shown that the most responsive inputs to road user costs and benefits are: new vehicle cost, kilometres driven per year, service life, maintenance labour cost, gross vehicle weight, fuel cost, new tire cost, number of passengers and passenger time cost (Archondo – Callao, 2008).

The vehicle types used in all overload cases were obtained from As Built Pavement Report of AAAEW. However, the equivalent axle load factor and number of overloaded trucks vary among overload cases as discussed in section 5.2.8. Accordingly, a single vehicle fleet with sixteen (16) vehicle types was defined with prefix VAA-ADEW as presented in Appendix D2.

Economic and other data of vehicle fleet was obtained from ERA Economic Section. These parameters were assumed to remain constant for all overload cases. Detailed vehicle characteristics and road user costs data is provided in Appendix C.

### 5.2.10. Analysis Period

The design period of asphalt pavement is 15 years as per Chinese specification. However, the design life of roads with functional class above main access road is 20 years as per Ethiopian Pavement Design Manual (2002). Finally the, the design ESAL of AAAEW was calculated for 20 years as per the contract agreement (CCCC, *As built pavement report*, 2014).

The CCCC inked a deal with the Ethiopian Roads Authority (ERA) in June 2009 and commenced the construction in April 2010. The road was finalized and inaugurated in May 5, 2014. Accordingly, analysis period of 20 years was considered starting on year 2015. The road Condition for the year 2014, a beginning of service year, was taken as default values for new asphalt road. The construction period was taken as 4 years starting from 2010. Other time related data of HDM 4 are presented in summary of data section.

### 5.2.11. Design ESAL

According to predicted traffic volume, traffic growth rates, vehicle proportion and the weighted ESAL coefficients, cumulative ESAL within design period per single lane was calculated. After the initial ESAL, ESAL<sub>0</sub>, was determined; Equation 5.5 was used to calculate the total ESAL over design period (CCCC, *As built pavement report*, 2014). It can be seen that the expression uses a total growth formula recommended by AASHTO and ERA.

$$N_e = \frac{((1+r)^t - 1) * 365 * N_1 * \eta}{r} \dots\dots\dots 5.5$$

Where

- Ne: Cumulative ESAL over design life per lane
- t: Design Life (20Years)
- η: Lane distribution factor (0.3)
- r: annual average traffic growth rate within design period
- N<sub>1</sub>: Two way daily average ESAL<sub>0</sub> at the beginning of service year (2014)

According to As Built Pavement Report by CCCC (2014), the lane coefficient (η) incorporates both directional and lane wander factors. Consequently, two-way ESAL was multiplied by lane coefficient (η) to determine design ESAL per lane. Details of cumulative ESAL calculated based on Chinese specification, which was used for pavement design, can be found in As Built Pavement Report (2014).

### 5.2.12. Pavement Design and Selected Profile

A Chinese specification was used in pavement design and construction. The bases for determination of pavement scheme include the traffic volume & distribution of interchanges, route topography and local materials, Chinese specifications and main failure modes of roads in Ethiopia (CCCC, *As built pavement report*, 2014).

Besides, clients agreement and six (6) years warranty bond after taking over the project were also considered (CCCC, *As built pavement report*, 2014). Performance criteria is to set specification to control skid resistance, roughness, cracking, rutting, ravelling etc before reaching design life time instead of guidelines type specification (Molenaar, 2006). If pavement performance is a prime subject in a contract, then the design and material selection should be done by the contractor, probably together with a qualified consultant, given the constraints set by the road authority (Molenaar, 2006).

Besides other things, this could be the basic reason why the project was design and build type. The Expressway was designed and built by the China Communications Construction Company (CCCC) and consulted on by the Beijing Expressway Supervision (BES). The role of ERA in the project was minimal supervision.

#### 5.2.12.1. Pavement Design Concept

Pavement Design Software HPDS2006 which is prepared based on Chinese specification was used for pavement analysis. The pavement structure is assumed as continuous elastic layer system. Mechanistic analysis was performed on the layer subjected two-wheel loads, circularly uniformly distributed vertical load as shown demonstrated in Figure 5.7 (CCCC, *As built pavement report*, 2014).

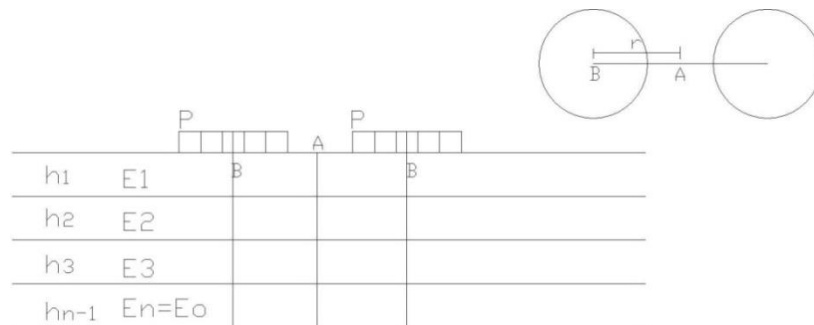


Figure 5.7: Axle load and Analysis Points Used for Pavement Design

The pavement design was based on limiting surface deflection and tensile stress of the surface. Pavement surface course deflection value was used as design index. The compression modulus of resilience was used as design parameter with test for bituminous concrete at temperature of 20°C. The cumulative ESAL within design period is related to surface course deflection value using an equation with detail analysis is discussed in *As Built Pavement Report* (2014).

### 5.2.12.2. Selected Pavement Profile

According to As Built Pavement Report by CCCC (2014), materials considered for analysis of mainline pavement structure include:

- **Surface Course:** Wearing course of 4cm fine grained Asphalt Concrete (AC-13) and binder course of 6cm medium grained Asphalt Concrete (AC-20)
- **Base Course:** Flexible base HMAM-25 was adopted for the project.. HMAM was believed to have high strength, durability and wheel track resistance, and has long service years. It was selected based on suitability to local climate and practical condition.
- **Sub-base Course:** Graded macadam of thickness 32cm was used.

Materials and parameters used for analysis are presented in Table 5.6 as provided by CCCC (*As built pavement report*, 2014).

Table 5.6 Pavement Structure layer and Parameter Selection

Layer	Material	Thickness (cm)	Compression modulus (MPa) 20°C	Compression modulus (MPa) 15°C	Allowable Tensile Stress (MPa)
1	Wearing Course; AC-13	4	1500	2100	0.28
2	Binder Course; AC 20	6	1200	1800	0.23
3	Base Course; HMAM-25	?	1350	1600	
4	Sub-base; Graded macadam	32	350	350	
5	Capping layer; Earth base		Eo=60Mpa		

The non-uniform traffic volume of each section of entire road link affects the calculated base layer thickness of each. However, final optimization of pavement structure was performed based on performance requirement by ERA (client), wheel path associated Cracks and construction requirements. Changes made to original ERA specification are discussed in as built pavement report by CCCC (2014).

The final optimized pavement structure based on the analysis results, requirements of specification and construction structure for the main line was prepared as shown Table 5.7 5.2 (CCCC, *As built pavement report*, 2014).

Table 5.7 Selected pavement structure for the main line

Layer	BP-Modjo [ K2+800-K52+600]	Modjo-EP [ K52+600-K77+500]
<b>Wearing course</b> (50#Asphalt+Track resistant Additive )	4cm	4cm
<b>Binder Course</b> (50#Asphalt+ Track resistant Additive for sections with large gradient)	6cm	6cm
<b>Base Course</b> (50#Asphalt + High modulus additive paved by two layers)	17cm	16cm
<b>Sub Base</b> Graded macadam (paved by two layers)	32cm	32cm
Total Thickness	59cm	58cm

From Construction quality point of view, the degree of compactness of capping layer was  $\geq 96\%$  and for all the layers was  $\geq 98\%$  [5].

### **5.2.13. Summary of Road Sections Data**

Summary of road section data inputs used for HDM-4 analysis are summarized in Table 5.8.

Table 5.8 Summary of Road Sections Data

Addis Ababa - Adama Expressway Road link Data input for HDM-4							
Number	Category	Attribute   Description	Road Section Name and ID				
			Addis Ababa - North Debre Zeit [AA-DZ] [K2+800-K17+000]	North Debre Zeit - Modjo [DZ-MO] [K17+000-K52+200]	Modjo - West Adama [MO-AW] [K52+200-K60+500]	West Adama - Asela Road [AW-AR] [K60+500-K71+700]	Asela Road-End Point [AR-AD] [K71+700-K77+500]
1	General HDM-4 inputs	Length [Total Length 74km]	14	35	8	11	6
2		Road Condition	Good [IRI= 2m/km]				
3		Road Terrain Classification	Rolling [maximum gradient 5%]	Flat [maximum gradient 3.7%]	Flat and Rolling [Max gradient 5%]	Rolling [Maximum gradient 5%]	Rolling (maximum gradient 5%)
4		AADT & Traffic Composition	Look at Appendix D1 and D2 for Detail Traffic Data of Each Road Section and Each Overload Cases				
5		Traffic growth rate	Look table 5.3 for detail Traffic data of each road section				
6		Average Monthly Rainfall (mm)	79.02	73.42	75.38	74.20	73.03
7		Average Monthly Temperature (°C)	17.08	17.43	17.78	19.43	21.08
8		Climate Zone Type	Sub humid-Tropical	Sub humid-Tropical	Sub humid-Tropical	Sub humid-Tropical	Sub humid-Tropical
9		Altitude [correct with the help of vertical alignment IP]	2116	1863	1849	1650	1570
10		Carriage way width	2*3*3.75 [ A 6 lane, two way, 3 lane in each direction, with 3.75m lane width each and total width of 31m]				
11		Raised median width	2m	2m	2m	2m	2m
12		Shoulder width [one side]	2.5m	2.5m	2.5m	2.5m	2.5m
13		Last surfacing Year [Calendar Year]					
14		Speed Limit (km/hr)	100	120	120	100	100
15		Speed flow type	Free flow [Controlled access]	Access Controlled [Free flow]	Access Controlled [Free flow]	Access Controlled [Free flow]	Access Controlled [Free flow]
16		Traffic Flow pattern type	Free Flow	Free Flow	Free Flow	Free Flow	Free Flow
17		Construction quality	Good [For all layers degree of compaction>=98% for capping layer>96%]				

18		Superelevation	4.5%	2.5%	3.5%	4.5%	4.50%
19	<b>Drainage type</b>	Drain type	V-shaped hard	V-shaped hard	V-shaped hard	V-shaped hard	V-shaped hard
20		Drainage (excellent, good, fair, poor, very poor)	Excellent	Excellent	Excellent	Excellent	Excellent
21	<b>Geometric Type</b>	Horizontal curvature (degree/km)	21.17	10.68	11.04	21.87	21.12
22		Vertical rise + fall (m/km)	27.12	8.82	19.66	26.17	21.57
23		Wearing course type	Asphalt Concrete [AC]	Asphalt Concrete [AC]	Asphalt Concrete [AC]	Asphalt Concrete [AC]	Asphalt Concrete [AC]
24	<b>Surface Texture type</b>	Texture depth (mm) (Skrim at 50km/hr)	0.7	0.7	0.7	0.7	0.7
25		Skid resistance (mm)	0.5	0.5	0.5	0.5	0.5
26	<b>Structural Adequacy Type</b>	Wearing course thickness (mm)	100 [40+60]	100 [40+60]	100 [40+60]	100 [40+60]	100 [40+60]
27		Base type	HMAM	HMAM	HMAM	HMAM	HMAM
28		Base thickness (mm)	160	160	160	160	160
29		Sub base thickness (mm)	320	320	320	320	320
30		Structural Number, SN	4.64	4.64	4.52	4.52	4.52
31		Subgrade CBR (%)	6%	6%	6%	12%	16%
32	<b>Surface Condition Type</b>	All Structural Cracking (%)	0	0	0	0	0
33		Raveled Area (%)	0	0	0	0	0
34		Number of Potholes (No./km)	0	0	0	0	0
35		Mean rut depth (mm)	0	0	0	0	0
36		All Transverse Thermal Cracking (%)	0	0	0	0	0
37		Wide Structural Cracking Area (%)	0	0	0	0	0
38		Edge Break Area (m2/km)	0	0	0	0	0
39	<b>Road History (Calendar Year)</b>	Construction cost per km (ETB/km)					
40		Duration of work (years)	4 years	4 years	4 years	4 years	4 years
41		Analysis Start year	2015	2015	2015	2015	2015
42		Last rehabilitation	2010	2010	2010	2010	2010
43		Last Construction	2010	2010	2010	2010	2010
44		Last preventive treatment	2010	2010	2010	2010	2010

### 5.3. Overload Fine Analysis

Based on the current practice at Addis Ababa - Adama Expressway, overloaded trucks are immediately detected and were forced to return back. In this study, overloaded vehicles were ideally allowed to use the expressway, so their impact could be analysed. The Overload fine was considered as combination of two basic components. The first one is economic loss as a result of overloaded trucks and the second one is weighing stations overhead cost. Both concepts are discussed in detail in the following Sections.

#### 5.3.1. Introduction

The presence of overloaded trucks in the traffic mix affects originally programmed pavement performance. This in turn changes VOC, travel time and associated maintenance, rehabilitation interventions. However, these effects are interdependent and need to consider their combined effects instead of separate analysis.

Figure 5.8 illustrates pavement performance curves road section I (Addis Ababa – Debre Zeit) in downhill direction with and without intervention for Case 0 (normal traffic) and Case 1 (with 10% overloading per axle). The x-axis indicates the analysis year and the y-axis provides the corresponding average roughness (IRI in m/km) from HDM-4 programme analysis results.

Two methods could be used to compare the economic impact of Case 1 with respect to reference case (Case 0). In the first approach, comparison could be done based on do-nothing approach. This means, there will not be any periodic maintenance intervention regardless of the increase in road roughness. In this circumstance, Case 0 without intervention is compared with Case 1 without intervention. From Figure 5.8, it is clear that the road roughness under Case 1 without intervention would always be higher than Case 0 without intervention. Hence, in this approach, the economic loss due to overloading could be considered as the increase in vehicle operating costs and increase in travel time costs associated with increase in road roughness. However, road repair and maintenance are unavoidable as roads deteriorate as discussed in section 2.7.1. Therefore this approach of ‘Do- Nothing’ was rejected.

In the second approach, government agency, maintains roads to standard, to a desired level and overloaded trucks shall pay for benefits they accrue. From Figure 5.8, for similar limit in average roughness (IRI) of 4m/km, Case 0 would require a capital intervention of A3 (30mm Asphalt Concrete Overlay) in 2032, Whereas, Case 1 requires a capital intervention of A3 (30mm Asphalt Concrete Overlay) in 2030. This means that the case with overloaded trucks requires earlier intervention than without intervention.

Another point that could be observed is that the average road roughness (IRI) for Case 1 is higher than Case 0 at starting year until maintenance intervention in 2030. After intervention, the average road roughness (IRI) for case 1 is lower than Case 0 until intervention is applied in Case 0 in 2032. From 2032 up to the end of analysis period, the road roughness under Case 0 is lower than Case 1. The vehicle operating costs and travel time costs also follow similar trend as road roughness.

Analysing the impact of overloading in this case requires considering the type and timing of interventions in respect of benefits such as reduction in VOCs and travel time costs under each case. The combined effect of costs, benefits and time elements are converted into a common time which can be used for comparison. This unit is the net present value (NPV). The economic impact due to overloading is then considered as the difference in NPVs between Case 0 and other overload cases.

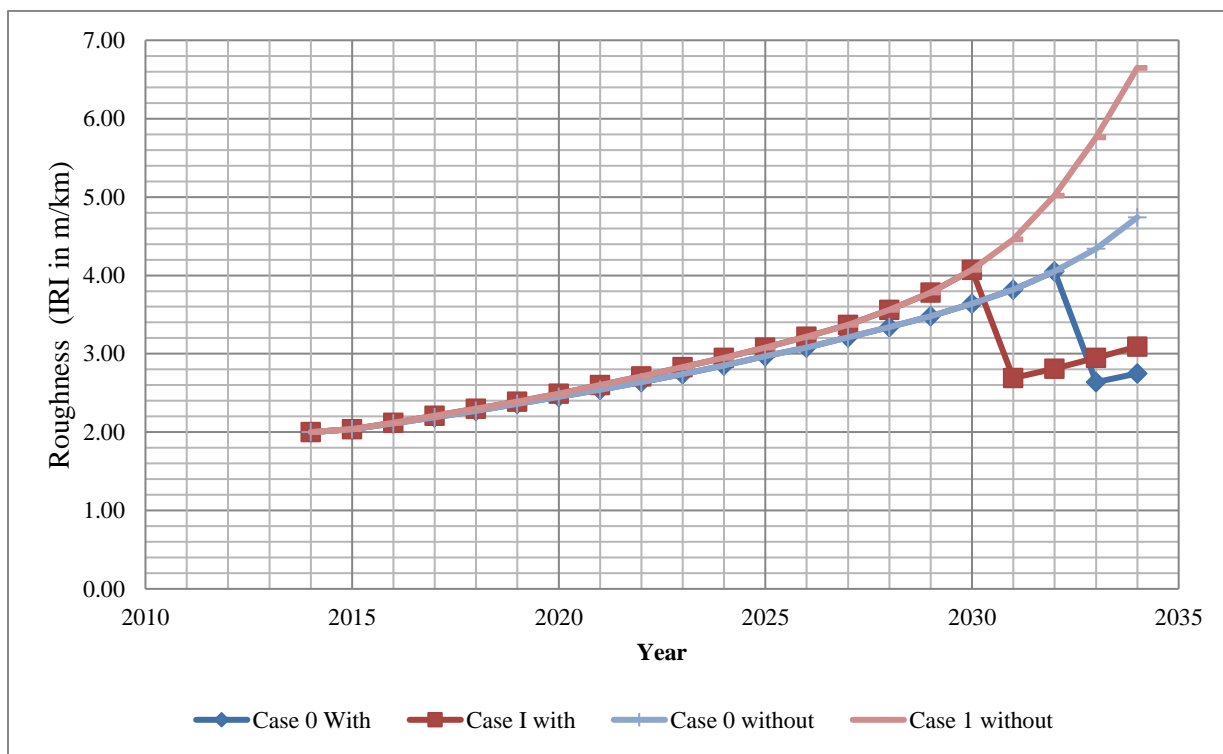


Figure 5.8 Pavement Performance Curve with and without intervention [Section I Downhill]

In this study, the second approach was utilised, optimum maintenance programmes required for analysis period of 20 years were first determined. Optimized maintenance standards under each overload case were then used to determine the NPV of each overload case using HDM-4 Programme Analysis. The difference in NPV between overloaded Cases and Case 0 was considered as the net economic impact due to overloaded trucks. The economic impact was then distributed to total number of axles to determine the economic impact per axle overloading per kilometre which is the base for determining rationalized overload fine.

### 5.3.2. Maintenance Standards

HDM-4 only evaluates the project alternatives defined by the user; accordingly, a different combination that was not defined by the user could yield a higher NPV/Cost. Therefore, the definition of the project alternatives is critical for acceptable evaluation. One approach taken to ensure a sound definition of project alternatives is to perform first a preliminary evaluation that evaluates each road class, all possible road works identified in the country (CCCC, *As built pavement report*, 2014).

In this study, routine and periodic maintenance standards practiced by ERA and AACRA were considered as an input in HDM-4. The maintenance programs considered in the study were routine and periodic maintenance.

**Routine Maintenance** was applied for pavement and non-pavement requirements. Routine maintenance were usually assigned each year and when necessary throughout the analysis period. Routine maintenance was considered under pavement and non-pavement characteristics:

- **Pavement Related Routine Maintenance:** Crack Sealing and patching are the most practiced approaches of pavement related routine maintenance in AACRA. HDM-4 also provides modelling of pavement strength and allows the effect of work to be evaluated. The routine works were applied responsive to condition of pavement related routine maintenance works considered during analysis.
  - **Patching and Crack Sealing includes two work items**
    - Patching: In HDM-4, patching is used to repair distress such as potholing, wide structural cracking and ravelling. Patching was applied when Potholing attains 1no./km.
    - Crack Sealing was applied remedial condition responsive to horizontal and transverse cracks. It was applied when wide structural cracking reaches 10%.
- **Non-Pavement Related Routine Maintenance** includes cyclic works related with:
  - Drainage: culvert repairs, clearing side drains etc and
  - Road Side Works: Shoulder repair etc.
  - Miscellaneous: Vegetation control, marking, signs, fencing etc.

All non-pavement routine maintenance works were considered to be conducted annually.

**Periodic Maintenance** is required based on road condition, traffic and roughness. Condition responsive periodic maintenance intervention based on roughness of the road was used for the study. Maintenance standards common in Ethiopia were considered for the study. Accordingly Asphalt Concrete Overlays of thickness 30mm – 80mm were considered under periodic maintenance.

A 30mm AC overlay represent minimum overlay thickness practiced in AACRA. A 50mm AC overlay is the maximum overlay thickness practiced in Ethiopia. Although an overlay thickness greater than 50mm could provide a lower overall life time maintenance cost, it was not practiced either in AACRA or in ERA for long road stretch due to budget limitation.

For overloaded cases, the cumulative ESAL exceed design structural capacity of the pavement before the end of analysis period of 20 years. Strengthening overlay would therefore be required before the end of analysis period. Hence, an asphalt overlay thickness between 60 and 80 mm were also considered as alternative maintenance strategies.

With thinner AC thickness, it would not be practical to expect that the future periodic maintenance will take place only a few years after the first intervention. Besides, more frequent periodic maintenance may create discomfort on road users which may in turn force them to use alternative route. This could result in lowering the Expressway's revenue. Hence, in this study an optimum periodic maintenance intervention were allowed be applied only once over analysis period of 20 years.

### 5.3.3. Cost of Maintenance Works

The total cost of road works estimated in economic terms is necessary for an economic evaluation of HDM-4. The study tried to access maintenance budget of the study area from the Ethiopian Toll Road Enterprise. However, the effort was failed due to lack of documented budget estimates on routine and periodic maintenance. Hence, engineering estimates were made for routine and periodic maintenances works of the expressway.

Engineering estimate of routine maintenance works was classified in to two groups. These were pavement related and Non-pavement related routine maintenance works. Unit costs of non-pavement routine maintenance works was obtained from the ERA Economic Section. Expected volume of works was estimated using field survey, Google Earth (2010) and As Build Design Report. Accordingly, the annual cost of non-pavement routine maintenance for all road sections was estimated to be ETB 31,500 /km per year per direction.

Engineering estimate of pavement related routine maintenance works and periodic maintenance alternatives were also performed. The unit costs used were based on unit cost of work items obtained from ERA, AACRA, private contractors and consultants at the time of the study. Most cost estimates obtained from the ERA Economic Section were below the actual market price whereas private contractors and consultants used for actual works. Actual cost of maintenance works for different projects was also higher than the ERA estimated budgets. On the other hand, unit price of works estimated by contractors was higher as compared to others. In this study cost estimation of pavement related works was made by taking the average direct cost estimate of the three organizations: ERA, AACRA, and Contractors.

Indirect works costs that include costs related to management and administration was added using ratio of direct works costs. The ratio combines certain percentage of project overhead, profit margin and others. The ratio was estimated based on the current practice by Consultants, Contractors, and AACRA & ERA. In most cases the indirect cost was estimated 25%-35% of direct cost. Accordingly average value of 30% was adopted for this study.

Estimated maintenance costs were finally used in annual work plans and economic analysis of HDM-4. Summary of estimated cost of alternative maintenance strategies considered for analysis is presented in Table 5.9.

Table 5.9 Economic and Financial Cost Estimate of Works used for the study

N <sup>o</sup>	Description	Unit	Economic Cost [ETB]
1	Non Pavement Routine Maintenance per year-per km -per direction	Total	31,500
2	Pavement Related Routine Maintenance		
2.1	Patching with Shape Correction	M <sup>2</sup>	135.01
2.2	Crack Sealing	M <sup>2</sup>	32.78
3	Pavement Related Routine Maintenance Alternatives		
3.2	Double Bituminous Surface Dressing	M <sup>2</sup>	109.25
3.3	30mm Asphalt Concrete Overlay	M <sup>2</sup>	171.73
3.4	40mm Asphalt Concrete Overlay	M <sup>2</sup>	216.98
3.5	50mm Asphalt Concrete Overlay	M <sup>2</sup>	259.22
3.6	60mm Asphalt Concrete Overlay	M <sup>2</sup>	301.46
3.7	70mm Asphalt Concrete Overlay	M <sup>2</sup>	406.03
3.8	80mm Asphalt Concrete Overlay	M <sup>2</sup>	447.78

Note: ETB=Ethiopian Birr, AC=Asphalt Concrete  
 Cost includes both direct and indirect costs

Abdisa (2011), in his study on commercialization of roads in Ethiopia, has considered annual inflation, escalation rate of 5% on estimated cost of works. However, detailed justification behind this assumption was not provided. Determination of inflation requires analysis of escalation in costs of road works and escalation in associated with road user benefits. In this study, escalation in costs and benefits associated with road works were assumed to be in balance. Hence inflation was not considered in HDM-4 Programme Analysis.

### 5.3.4. Alternative Maintenance Strategies

HDM-4 allows for the definition of condition-responsive and scheduled maintenance alternatives. Purely condition-responsive or purely scheduled maintenance alternatives are not recommended (31). Fixed time interval between maintenance interventions may not provide the desired pavement performance as the interval between roads works should change over time on account of traffic growth and environmental conditions. The same types of road works for the entire design period may not also be reasonable from economic point of view (Archondo – Callao, 2008).

It is therefore recommended to combine both condition responsive and scheduled maintenance works in determining optimum strategies. In this study, a condition responsive alternative was primarily considered in determining optimal strategies. However, the effect of scheduled maintenance intervention on pavement performance was also considered in determining the final project budget.

Non-pavement routine maintenance works were applied every year. Pavement related routine maintenance and periodic maintenance works were applied based on condition of the road.

The international roughness index (IRI) was used as intervention criterion for periodic maintenance works. Different values of roughness (IRI) along with each maintenance alternatives were considered as possible maintenance strategies. Since the study road is an expressway, a maximum roughness value of 5 m/km as an IRI value was considered as a trigger value.

Road works code with two (2) characters was used to make it easier to identify HDM-4 solution of each road section just by looking at alternative’s name. For example, alternative **A1** indicates the alternative to apply RM + 30mm Asphalt Concrete Overlay at 3 IRI. Table 5.10 presents a list of alternative maintenance strategies used in the study.

Table 5.10 Alternative Maintenance Strategies Considered For Analysis

Periodic Maintenance Options	Trigger Points [IRI(m/km)]				
	IRI=3	IRI=3.5	IRI=4	IRI=4.5	IRI=5
	<b>3 [1]</b>	<b>3.5 [2]</b>	<b>4 [3]</b>	<b>4.5 [4]</b>	<b>5 [5]</b>
RM+30 mm Asphalt Concrete Overlay [A]	A1	A2	A3	A4	A5
RM+40 mm Asphalt Concrete Overlay [B]	B1	B2	B3	B4	B5
RM+50 mm Asphalt Concrete Overlay [C]	C1	C2	C3	C4	C5
RM+60 mm Asphalt Concrete Overlay [D]	D1	D2	D3	D4	D5
RM+70 mm Asphalt Concrete Overlay [E]	E1	E2	E3	E4	E5
RM+80 mm Asphalt Concrete Overlay [F]	F1	F2	F3	F4	F5

Note: RM=Routine Maintenance [Pavement and Non Pavement Routine Maintenance]

Road marking was also applied along with each periodic maintenance works.

### 5.3.5. Maintenance Work Effects

The effect of road works can be seen at two levels; the first one is in terms of immediate effects of works and the second one is the long term effects of works. HDM-4 provides models with reset values for considering immediate impact of road works. Deterioration models which simulate long term effects are also part of HDM-4. The work effects are developed partly through field observation and with the help of computer simulation.

Adjusting model parameters to local condition requires calibration, which will enhance the accuracy of HDM-4 output. Different levels of calibration could be performed. Level 1 calibration requires determining basic input parameters, adopts many default values, and calibrates the most sensitive parameters with best estimates, desk studies or minimal field surveys. Level 2 and level 3 calibrations require selecting road section and monitoring the actual progress of different parameters. This allows correcting parameters to adjust what is predicted and what is actually observed.

In the Study, it was not possible to find higher level of calibrations at ERA. Therefore, the HDM4 Version 1.1 along with Level 1 calibration was used in this study. Reliable data was collected regarding overload pattern, road link characteristics, vehicle operating costs, maintenance standards costs, etc. Other parameters related to the effect of road works and road deterioration models were used as defaults specified in HDM-4. Higher level calibrations require further adjustments of parameters of models using field roughness observation, which is beyond the scope of this study.

The effect of pavement related routine maintenance (patching and crack sealing) was applied using default values of HDM-4. The effect of asphalt concrete overlays on roughness can be predicted using Bilinear or Generalized Bilinear models of HDM-4. In this regard, it is recommended to use a bi-linear model because the simplified linear model does not adequately consider the dual effect of overlay [20].

The Bilinear Model provides the relationship between overlay and roughness as a function of pavement type, thickness of overlay and overlay execution technique. The Bilinear Model also provides the total reduction in roughness (IRI) as a function of road roughness before intervention and user-defined coefficients. In this study, the effect of different alternative maintenance strategies on roughness was derived using Bilinear Model of HDM-4 along with default model coefficients. Detail of the work effects and deterioration models can be found in HDM-4 Volume 6 Guide for modelling road deterioration works (2004).

### 5.3.6. Optimizing Maintenance Standards

During the study, it was not possible to find optimized maintenance standard of the Addis Ababa - Adama Expressway. Accordingly, the HDM-4 Programme Analysis was performed for AAAEW road link to identify optimum standard among alternatives matrix shown in Table 5.10 above.

All maintenance strategies result in costs to the agency and a change to the condition of the road. The change in condition of the road provides immediate benefit to road users. It also reduces deterioration; maintenance needs in the future and hence lower long-term costs to the agency. By comparing initial costs and the immediate and long-term benefits, the economic efficiency of the type and timing of the operation can be evaluated (Morosiuk et al, 2004).

The HDM-4 lifecycle Programme Analysis was performed for each overload case and for each road section in both directions of the road. Several HDM-4 iterations were made with start period being 2015, analysis period of 20 years and discount rate of 11% (ERA practice). Each HDM-4 programme analysis provides work programs along with other outputs.

The NPV/cost, economic priority indicator, and timing of all standards was determined for each road section in both directions. The maintenance strategy that gives the highest NPV/cost was primarily selected as optimum maintenance strategy for a road section. Engineering judgment was however used to evaluate the final maintenance strategy of each road section. This involves keeping the maximum frequency of intervention only once over analysis period. The above procedure was repeated for each overloading case. Selected optimum maintenance strategy was finally used to determine the NPV of each road section which served as means of determining rationalised overload fine. The whole process of optimizing maintenance standards is as illustrated in Figure 5.9.

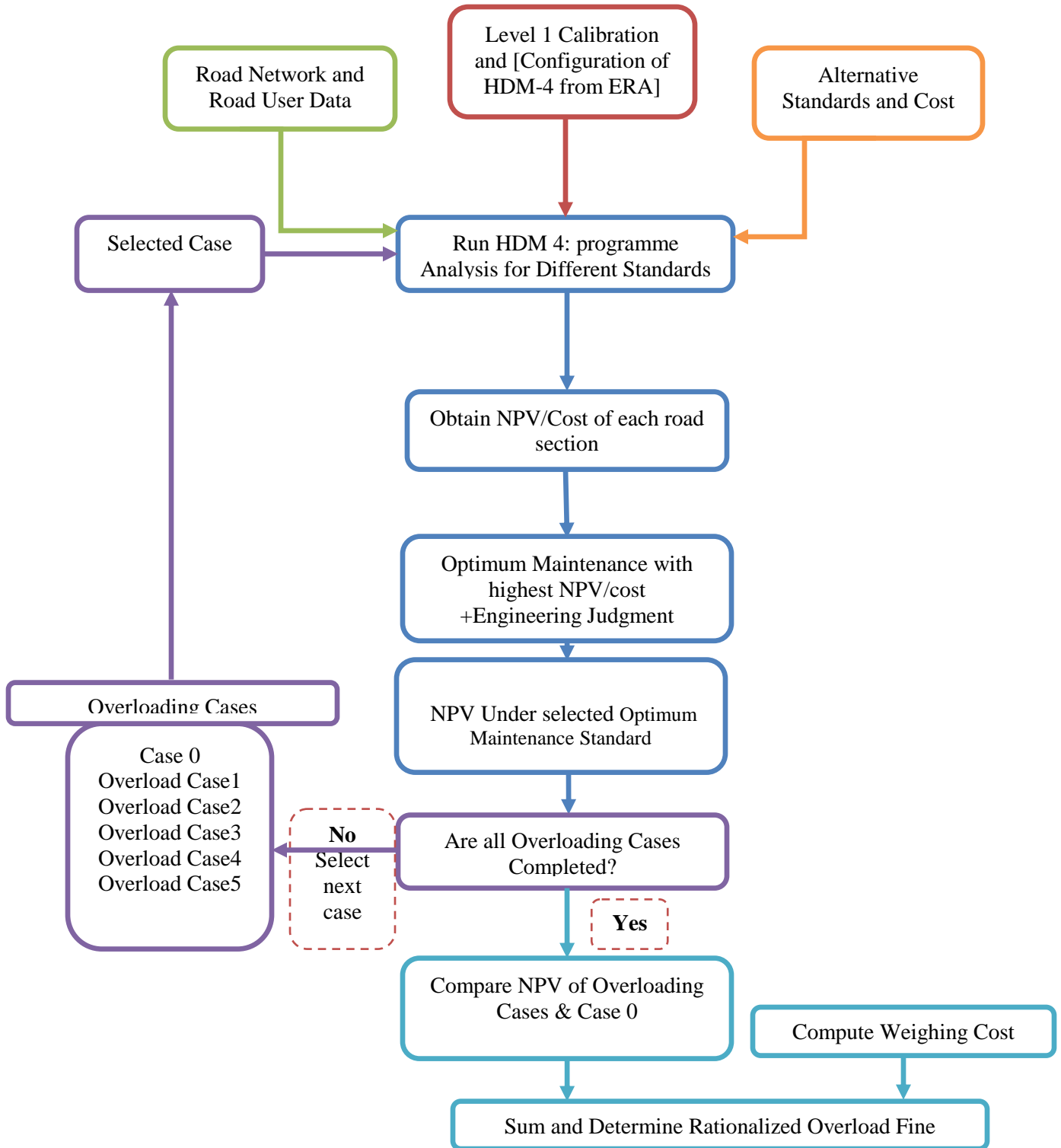


Figure 5.9 Procedure used for Determining Optimum Maintenance Standard

### 5.3.7. Selected Maintenance Standards

Three steps were used in selecting the final maintenance standard. In first step, optimum maintenance intervention was selected as the one with highest NPV/Cost among several iteration results. For example, for the road section Addis Ababa to Debre Zeit, Overload Case 1, the optimum maintenance standard that gives highest NPV/cost is A3 as depicted in Figure 5.10.

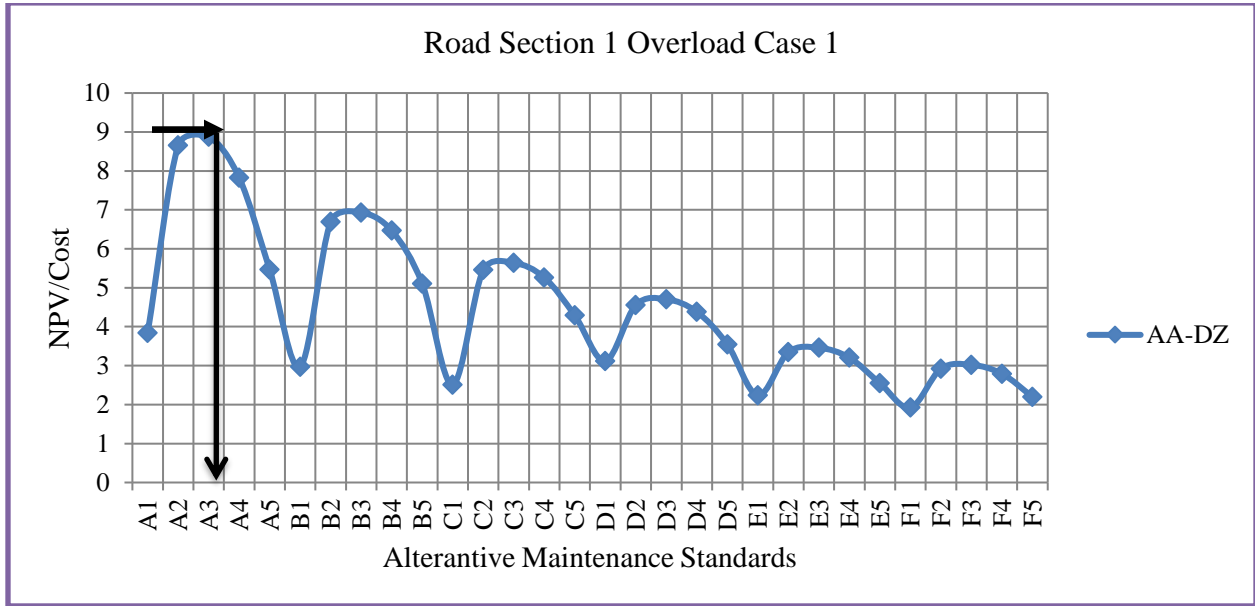


Figure 5.10 Optimizing Maintenance Standard Based on Maximizing NPV/Cost

A similar approach was followed for the remaining cases and optimum maintenance standards were determined. Appendix E provides iteration results for each overload case and for each road section along with selected maintenance standards.

In the second step, roughness (IRI) values that are used as trigger values for all sections were harmonized into a single value since it was required to compare NPV of different overload cases based on similar level of service. Accordingly, the optimum trigger values from step 1 were weighted based on the total length of the road under each alternative case. The IRI values that were selected for most sections and most overload cases were used as trigger values for the entire road link. Table 5.11 demonstrates the selected intervention values.

Finally, the optimum maintenance strategies selected in step 1 were then reviewed based on common intervention value of 4.0m/km, selected in step 2, and to limit the frequency of interventions to only once over design period of 20 years to avoid inconvenience to road users due to repetitive road works.

Table 5.11: Selected Common Roughness Value

Code (for trigger value)	IRI (m/km)	Selected on road length (frequency in km)	Proportion
1	3.0	0.00	0.00%
2	3.5	189.00	23.80%
<b>3</b>	<b>4.0</b>	<b>381.00</b>	<b>47.98%</b>
4	4.5	224.00	28.21%
5	5.0	0.00	0.00%
Total		794.00	100.00%
Selected trigger value 4.0 m/km [Code 3]			

The final selected maintenance standards that satisfy the above criteria was discussed above. These interventions were finally used to develop pavement performance curves and NPV of each road section under each overload case as shown in Table 5.12.

From Table 5.12, it is clear that road section V (Asela Road- Adama) required no intervention in both direction of traffic because the average roughness (IRI) in all overload cases was below 4m/km. For the remaining road sections, intervention type A3 (30mm Asphalt Concrete overlay at 4m/km (IRI)) is widely selected intervention type. The period of intervention has generally decreased with increase of overload case. Besides, in Section II (Debre Zeit - Modjo), intervention type has changed from A (30mm Asphalt Concrete Overlay) to B (40mm Asphalt Concrete overlay) and to C (50mm Asphalt Concrete overlay).

Hence overloading trucks caused earlier frequent intervention and sometimes a change in type of intervention required to keep the desired standard of the road.

Table 5.12 Selected Optimum maintenance intervention

Overload Case	Selected Periodic Maintenance standard				
	Road Section				
	Addis Ababa to Adama Direction				
	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
W/out Overloading	A3 in 2032	A3 in 2031	A3 in 2033	NR	NR
Overload Case 1	A3 in 2030	A3 in 2029	A3 in 2030	A3 in 2032	NR
Overload Case 2	A3 in 2029	A3 in 2028	A3 in 2029	A3 in 2031	NR
Overload Case 3	A3 in 2028	A3 in 2027	A3 in 2028	A3 in 2030	NR
Overload Case 4	A3 in 2028	B3 in 2027	A3 in 2028	A3 in 2030	NR
Overload Case 5	A3 in 2028	B3 in 2027	A3 in 2028	A3 in 2030	NR

	Adama to Addis Ababa Direction				
	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
W/out Overloading	A3 in 2032	A3 in 2030	A3 in 2033	NR	NR
Overload Case 1	A3 in 2030	A3 in 2027	A3 in 2030	A3 in 2033	NR
Overload Case 2	A3 in 2029	B3 in 2026	A3 in 2029	A3 in 2031	NR
Overload Case 3	A3 in 2028	C3 in 2025	A3 in 2028	A3 in 2031	NR
Overload Case 4	A3 in 2028	C3 in 2025	A3 in 2028	A3 in 2030	NR
Overload Case 5	A3 in 2028	C3 in 2025	A3 in 2028	A3 in 2030	NR

NR; Intervention not required (IRI<4.0m/km)

Source; Results of study

### 5.3.8. Economic Impact of Overloading

HDM-4 Life cycle Programme Analysis of AAAEW Road Link was performed using HDM4 Version 1.1 using optimized maintenance standards. Twelve (12) programs were created for six overload cases in both directions of traffic. The net present value (NPV) of investment cost of each overloaded case with intervention was determined against the base case without intervention. Each programme has the following two alternatives:

- Programme x;
  - Alternative 1: Case x with intervention
  - Base Alternative: Case x without intervention

Where x is particular overload case under consideration ( $x = 0, 1, 2 \dots 5$ ).

Accordingly, future pavement performance and associated NPV of each section under each overloading case were determined. All pavement performance curves produced during the study are summarized and presented in Appendix F. The resulting NPV of each road section under each overload case is presented in Table 5.13.

In general, the NPV has increased in parallel with increase in overload case. Under normal traffic (Case 0) the road would serve 20 years with or without the need for any capital intervention. This implies that, the effect of optimum intervention in the case of overloading, without intervention is higher than case without overloading and without intervention.

The increase in NPV values indicate the benefit to governments to intervene than doing nothing. The increase in difference of NPV with overload cases also represents the increase in economic benefit of overloaded trucks as a result of intervention since VOCs decrease. It also describes the economic loss in vehicle operating costs that could happen because of increased road roughness (IRI) without interventions. Accordingly, the difference in NPV of each overloading case with respect to the base case (Case 0) was considered as economic impact due to overloading. Table 5.13 shows the summary of NPVs generated using HDM-4.

Table 5.13 HDM-4 programme analysis NPV summary

Road Section	HDM-4 Programme analysis NPV (millions) - outputs					
	Overload Case Direction; Up Hill					
	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
I [AA-DZ]	12.56	51.84	73.62	97.54	98.56	99.62
II [DZ-MO]	165.52	570.45	736.38	886.35	897.38	910.28
III[MO-AW]	0.83	17.64	29.19	38.12	38.96	39.13
IV[AW-AR]	0	1.45	12.26	15.19	22.59	23.62
	Direction; Down Hill					
I [AA-DZ]	10.51	49.00	72.04	95.49	96.93	106.65
II [DZ-MO]	45.12	172.17	242.60	314.54	336.2	337.91
III[MO-AW]	0.14	13.97	24.46	32.93	33.51	33.71
IV[AW-AR]	0	5.69	14.96	24.17	24.76	29.46

Source; Results of Study

### 5.3.9. Distribution of Economic Impact to Overloaded Axles

Economic analysis with design traffic (Case 0) served as a reference to determine relative damage caused by overloaded trucks under each overload case. By comparing NPV of different overloaded cases against the base case without overloading, the amount of economic impact caused by overloaded trucks to a particular level was estimated.

The AADT of overloaded trucks for overloaded vehicles, under each overload case and each year within analysis period was primarily determined from proportion and pattern of overloaded trucks as discussed in section 4.7 3. Annual growth rates of overloaded trucks were also assumed to be similar to corresponding vehicle type in Table 5.3. The number of overloaded axles was then predicted by multiplying the AADT of each overloaded vehicle type by the number of axles assumed per vehicle. Three axles per heavy vehicles and six axles per truck and trailer were assumed as discussed in Section 5.2.8.

The number of overloaded axles varies over different years within the analysis period. In addition, revenue to be collected from overloaded axles has to be collected over time. Accordingly, the NPV of the total number of overloaded axles under each overload cases was calculated using internal rate of return of 11% (similar to the one used in programme analysis).

The change in NPV, resulted from HDM-4 Programme Analysis, between overload case and base option (Case 0) was finally distributed to the NPV of overloaded axles over the analysis period of 20 years. The procedure of distribution is sequential approach which is described in section 3.3.5. A simple EXCEL program was also prepared to help in cost distribution.

The cost of overloading per axle on Road Section V was 0 in both directions due to strong subgrade and oversized pavement structure for low traffic volume, as specified. Referring to pavement performance curve in Appendix F, none of the overloaded cases under road section V reach the specified average roughness (IRI) of 4m/km. There was no need for additional periodic maintenance and pavement related routine maintenance works. Accordingly, there is no additional cost to the road agency and it is rational to have zero (0) cost of overloading.

For the remaining sections, different values were assigned for similar rate of overloading on different sections. This has to do with several factors involved during analysis but, subgrade strength, pavement strength and corresponding traffic volume are the most important ones. Table 5.14 presents a summary of the results of the analysis. Detail of distribution of economic impact per axle per kilometre is presented in Appendix G1.

Table 5.14 Economic Cost per Overloaded Axle per Kilometer

Road Section	Cost (ETB per km per axle)	Overloading per axle					
		0%	10%	20%	30%	40%	50%
I (Uphill)		0.00	0.27	0.58	1.29	1.39	1.62
I (Downhill)		0.00	0.28	0.57	1.27	1.41	3.49
II (Uphill)		0.00	0.75	1.27	2.39	2.66	3.36
II (Downhill)		0.00	0.29	0.58	1.25	1.91	2.03
III (Uphill)		0.00	0.22	0.47	0.92	1.06	1.12
III (Downhill)		0.00	0.18	0.40	0.83	0.92	0.99
IV (Uphill)		0.00	0.02	0.18	0.29	1.17	1.44
IV (Downhill)		0.00	0.05	0.19	0.5	0.57	1.75
V (Uphill)		0.00	0.00	0.00	0.00	0.00	0.00
V (Downhill)		0.00	0.00	0.00	0.00	0.00	0.00

Source; Results of the Study

### 5.3.10. Weighing Stations Cost

If every truck operator respected specified axle load regulation, axle load control wouldn't be necessary. Since enforcement of regulation is required and weighing stations are in place, initial investment and recurrent costs of weighing stations should be included in overload fine analysis.

This approach allows weighing stations to be self-financing through revenue collected from overloaded trucks. It also discourages weak overload management, as the income of weighing stations comes from controlling overloaded trucks.

Weighing station initial investment, operation and management cost was estimated based on existing cost of the Modjo and new weighing stations under construction in the Country. Initial investment of a weighing station includes basic infrastructures such as access ramp, weighing machine, office blocks, guards' station, control cars, office furniture etc. Workers' residential building and electric power access could also be necessary for weighing bridges that are to be located outside urban sections.

Based on ERA road asset management section, initial investment for weighing stations, excluding staff residence was estimated at ETB 20 million. Regarding Weighing stations operational cost, annual running cost of Modjo weighing station was used as a reference. The number of Station officers at Modjo weighing Station is the largest of all weighing stations in Ethiopia. This could be due to large traffic volume and manpower requirement of weighing machine recording. A new weigh in motion weighing machine which provides automatic recording and print report was assumed in predicting operational cost. Accordingly to the weighing stations annual management cost, Birr 717,600 was used as indicated in Table 5.15.

Table 5.15 Estimated Annual Weighing Station Management cost

Nº	Description	Quantity	Monthly Cost [ETB]	Annual total Cost [ETB]
1	Station Head	1	6000	72000
2	Station officers [Record and Control Officer]	6	3000	216000
3	Driver	2	2000	48000
4	Guard	6	1500	108000
5	Cleaning Staff	1	1500	18000
6	Annual Calibration Cost	1	30000	30000
7	Office Consumables	12	5000	60000
Sub Total 1				552,000
Other costs [30%] [Electricity, fuel, Generator...]				165,600
Total				717,600

Note, ETB: Ethiopian Birr

Source; Analysis Modjo Weighing station and ERA Road Asset Management Section

Estimated weighing stations cost was then distributed equally to the total number of overloaded trucks regardless of the rate of overloading because, all overloaded vehicles consume similar service at weighing station. The number of overloaded trucks varies at different sections of the Addis Ababa - Adama road Link. Consequently, the average number of overloaded trucks was used for cost distribution purpose. The result of analysis requires weighing stations cost of ETB 14.67 per overloaded vehicle.

Summary of Cash Flows and Cost Distribution of Weighing Stations Cost on overloaded trucks is given in Appendix G2.

#### 5.4. Comparison of Rationalized Overload Fine with Court Imposed Overload Fines

Comparison was also made between court imposed overload charges and corresponding rationalised overload fine. A random sample of about two hundred (186) overloaded vehicles, which were charged in September 2013, was considered for analysis. Trucks with overloaded axle beyond 50% were excluded from comparison for analysis. Trucks (28) whose origins were at Modjo were also excluded from analysis because economic cost would be set to zero due to zero distance between the origin and weighing station. Comparison was then made between rationalised and court imposed overload management Costs on the remaining 158 overloaded vehicles.

As the basis for lying overload charges in the court system are mostly unknown, comparison was made based on re-evaluation of Court imposed overload fines using rationalized overload fines developed. In order to simplify overload fine analysis, the overload charges listed in Table 5.15 were combined based on principle of weighted average of road fine and corresponding road length. As the proportion of overloaded trucks in opposite directions of traffic was unknown, Separate overload fine structure was used to opposite directions of traffic. Accordingly, the results shown in Table 5.16 were prepared.

Table 5.16 Weighted Average Overload Fine Structure Used for Comparison

Percent Overload per Axle	0%	10%	20%	30%	40%	50%
Uphill [Adama towards Addis Ababa]						
ETB per km per axle	0.00	0.47	0.86	1.65	1.97	2.43
Downhill [Addis Ababa towards Adama]						
ETB per km per axle	0.00	0.24	0.49	1.08	1.47	2.16

The total overload fine per vehicle includes the sum of cumulative of overload fine on overloaded axles and weighing station cost per vehicle as it is given in Equation 5.6. The cumulative of overload fine of axles is the sum of overload fine of individual axles of the vehicle multiplied by the total distance the vehicle travels from its origin to the weighing station. On the other hand, weighing stations cost of 14.67 ETB per overloaded vehicle was used.

$$F_x = \sum_{i=0}^{i=n} L * Y_{xi} + W_c \dots\dots\dots 5.6$$

Where  $F_x$  = Rationalized Overload Fine on vehicle  $x$

$L$  = Total distance travelled by the vehicle (distance between origin and weighing station)

$Y_{xi}$  = Overload fine on  $i^{th}$  axle determine by equation 5.7 and 5.8

$i$  =  $i^{th}$  axle of vehicle  $x$

$n$  = total number of axles in vehicle  $x$

$W_c$  = Weighing Station Cost (=14.67 ETB)

Table 5.16 provides overload fine at 10% interval; however, axles that are overloaded in between require interpolation. In order to allow easier prediction of costs in between specified overload cases, best fitting curves were developed using EXCEL (trend line analysis). Accordingly, a least degree polynomial which is best representative and the one with higher correlation coefficient ( $R^2$ ) were selected as shown in Figure 5.11.

Accordingly the following equations were developed and used to determine overload fine

For Uphill direction

$$Y_{x_i} = a * (-14.12X_i^3 + 9.991X_i^2 + 3.344X_i + 0.006) \dots 5.7 \text{ (Source; results of the study)}$$

For Downhill direction

$$Y_{x_i} = -1.915X_i^3 + 6.431X_i^2 + 1.559X_i \dots\dots\dots 5.8 \text{ (Source; results of the study)}$$

Where;  $Y_{x_i}$  = overload fine on  $i^{th}$  axle

$X_i$  = Percent of overload per axle

$a$  is a dummy variable used to set zero cost or zero overloading  $a = 0$  if  $X_i \leq 0\%$   $a = 1$  if  $X_i > 0\%$

**Note:** These equations were only used to represent overloading up to 50%. It does not represent overloading beyond this limit and extrapolation beyond 50% overloading is unreliable.

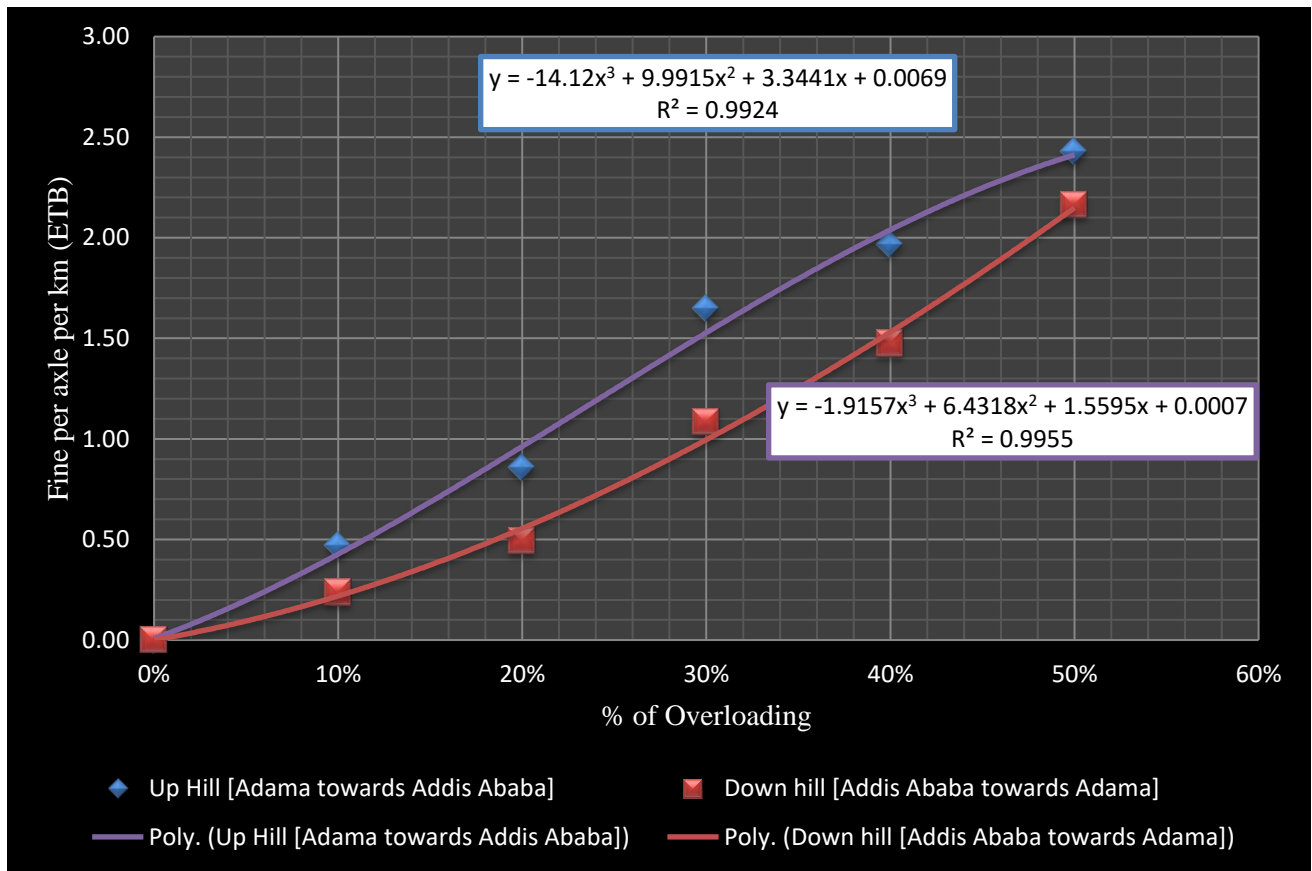


Figure 5.11: Best Fit Curves and Equations Used for Comparison of Overload Fines

Based on Equation 5.6, 5.7 and 5.8, rationalised overload fine of a random sample of 158 overloaded trucks was analyzed. Figure 5.12 illustrates the rationalized overload fines and court imposed fines. Detail analysis is presented in Appendix H.

The total distance between their origin and weighing station was estimated using Ethiopian road network map and data obtained from ERA. The comparison between rational and court imposed overload fine was made assuming overloaded trucks would unload extra weight at weighing station. This principle should be strictly adhered unless a special permit is given to proceed with extra weight. In case a special permit is given, the distance for fine analysis should be taken between origin and destination of trip.

Based on the results of the analysis, nearly a quarter (24.68%) of overloaded vehicles paid less than rationalized overload fine which is on average ETB 1098.03 below the rationalized fine. While, the three quarter (75.32%) of overloaded vehicles paid an average of ETB 280.82 more than rationalized overload fine. Only a few vehicles (8.86%) showed less than 10% difference to rationalized overload fee. Most vehicles have paid more than rationalized overload fine and difference in price between individual overloaded vehicles was also highly significant.

Gross revenue collected by court from sampled overloaded vehicles was also lower by ETB 7,240.00 (8.53 %) below rationalized overload fines. This result shows that the current court imposed fines are below what overloaded trucks were supposed to pay. Parameters used to compare the court imposed and rationalized overload fine are presented in Table 5.17.

Table 5.17: Summary of Statistical Comparison between Court-Imposed and Rationalized Overload Fines

Nº	Parameter	Court Imposed	Rationalized	Difference
1	Average Fine (ETB)	491.35	537.18	-45.82
2	Minimum Fine (ETB)	150.00	80.00	70.00
3	Maximum Fine (ETB)	4634	1000	3634
4	Gross Revenue (ETB)	77,634.00	84,874.00	-7835
24.68 % of overloaded vehicles paid less than rationalized fee On average -55.23% (-1098.03ETB) below rationalized fine.				
75.32% Vehicles who paid more than rationalized fee On average +186.08 % (+280.82ETB) above rationalized fine.				

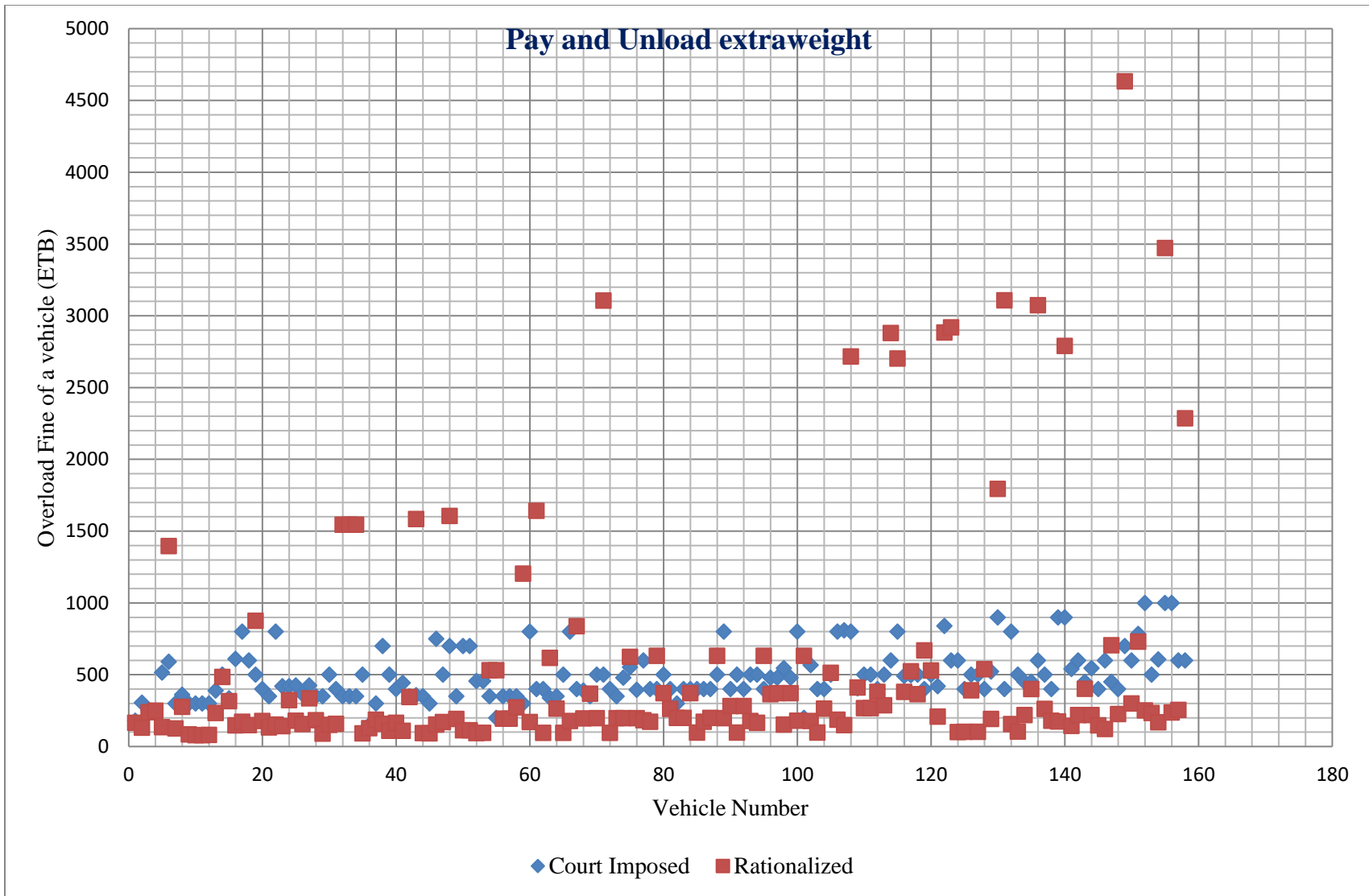


Figure 5.12 Court Imposed Vs Rationalized Overload Fine [Assumption Pay and adjust extra weight at weighing station]

## 6. CONCLUSIONS AND RECOMMENDATIONS

### 6.1. Conclusions

The purpose of this thesis was to determine rationalised overload fine (price/axle overload/km) considering the economic impact of overloaded trucks and overhead costs with respect to the Addis Ababa - Adama Expressway and regarded weighing stations, mainly the Modjo Weighing Station. The purpose was also to compare rational overload fine with current court-imposed overload fees and propose rationalised overload fine to be applied to protect the infrastructure of the Expressway.

A case study on road link (Addis Ababa – Adama Expressway) consisting five road sections was used to analyse the economic impact of overloaded trucks at six rates of overloading (0% - 50%). The HDM-4 Programme Analysis was performed for 20 years of analysis period. The result of the analysis showed an increase in road roughness (IRI) and associated VOC and travel time cost without maintenance or rehabilitation intervention. With optimum maintenance intervention however, overload cases required earlier intervention; thickness of overlay has also increased on some road sections.

The combined economic impact was therefore analysed by comparing NPVs. Most road sections have showed an increase in NPV with increase in overloads. The economic impact was also higher in most road sections in uphill (Adama to Addis Ababa) direction than the downhill direction.. This result is expected as pavement damage would be higher in uphill direction due to fully loaded slow moving heavy vehicles are more damaging than otherwise.

On the other hand, the road section V (Asela road - Adama) did not show any change in NPV on both directions. The pavement of this road section was overdesigned for observed low traffic and it is with good subgrade strength which made it capable of carrying traffic under all overload cases. Hence no economic impact was detected on this road section. This also shows that if pavements are overdesigned to accommodate overloaded trucks, there will not be any need for overload control. However the principle no weight control could not be applied on Ethiopian roads due to limited government budget for infrastructure.

Rationalized overload fine structure was then primarily prepared (fine per overload rate per axle per kilometre) based on economic impact. Overload management cost was also distributed equally regardless of the overloaded vehicle type.

Statistical comparison of court-imposed overload fines and rationalised ones was performed assuming overloaded trucks would adjust extra weight at weighing station. Results of comparison showed high difference in terms of individual fines. Roughly a quarter of overloaded trucks had paid on average only 44.77% (ETB 890) of rationalized overload fine while the remaining (75.32%) overloaded vehicles had paid on average 186.08% (ETB 280.82) more than what they should have paid. In terms of gross revenue collected from sample overloaded trucks, the actual collected revenue is 8.53 % less than what is expected of rationalized fines. Although the difference in terms of gross revenue might seem small, the impact would be significant when other costs related to overload, such as bridge damage and safety costs are included.

This study is expected to lay a foundation for scientific approach of determining overload charges in Ethiopia and beyond. The procedure could also be used in special permits considering economic impact, including bridge damage cost and any other service charges. However overload fine structures must be regularly updated considering up to date data.

## 6.2. Recommendations

Overload management should be seen as part of Road network management as integrated approach is required to maximize the efficiency of transportation. The following recommendations are forwarded to prevent overloading in Ethiopia

### (i) Legislation Change

- The use of court to impose overload fines has not proved effectiveness in terms of preventing overloading. Hence, a legislative change is required with transfer of enforcement power from local courts to concerned road management agency.
- The court procedure would not take only a significant amount of transporters' time but also imposes unjustified fines. On the other hand, gross revenue collected from overloaded trucks is less than what is expected to commensurate the impact of overloaded trucks, which adversely affects the cost recovery of road infrastructure provision to the country.
- The administrative approach also brings additional benefit to the road agency and transporters by letting them pay overload fines at weighing stations. The benefits to the vehicle operators can be seen in terms of saving time that would have been spent in the court process. The road agency also benefit from timely payment of overload fines which eliminates loss due to delay of payments as any vehicle will not pass unless the specified amount is paid and the axle load is adjusted to the legal limit.
- Any special permit and associated fee could be laid considering the economic impact and service charges by the authorized road agency.
- The revenue from overload fines should be deposited into the road management treasury and should be directly available for road maintenance and rehabilitation purposes. The use of automatic weighing stations, rationalised overload fine and efficient road management in general would make fines effective in terms of preventing overloaded trucks.

### (ii) Enforcement

- One of the challenges regarding axle load management is related to vehicles that change route to avoid the Modjo Weighing Station. Besides, some vehicles use night time and unfavourable weather to break the rule and pass Weighing bridges without having been checked. In order to prevent this, fixed weighing stations could be supplemented by mobile weighing machines and control stations. Fixed Weighing stations should also be operational 24 hours a day and seven days a week.

- Installation of Weigh in Motion Equipment; The weighing mechanism observed at Modjo weighing station. Heavy vehicles travelling on both directions are weighed at a single weighing station. Weighing a single vehicle requires a minimum of three personnel who work manual recording of every axle load and every vehicle plate number at minimum. This approach would not work during peak hours with long queue of vehicles on both directions. This approach takes more time and is tiresome to employers at weighing station. Therefore, a weigh in motion (WIM) equipment that provide automatic recording and print service is recommended.

**(iii) Awareness creation to major stakeholders**

One of the challenges is related to lack of awareness by drivers on effects of overloading to the road infrastructure. The problem is common among vehicle operators and government officials. Most vehicle operators lack awareness of damage scale caused by overloading and usually focus on net profit they make. Industries should be informed on how to self regulate overloading. For example, local cement producing companies and other heavy industries could install their own mechanism to control overloaded trucks. Higher government officials also influence the special permit process and lead to granting special permit without analysing the impact of unconventional load on road infrastructure. In order to prevent this, awareness creation program should be arranged and provided to major stakeholders.

**(iii) Vehicle Operators Self Regulation**

Most overloaded heavy trucks observed at Modjo Weighing Station were making trips within the country; transporting construction materials such as cement, steel, sand, agricultural products, commercial goods, etc. Commonly, two methods have been recommended by several studies how transporters could prevent overloading and these are:

- **Usage of more efficient vehicles**

Some unconventional loads might be unavoidable due to their contribution to the national economy. Heavy gross load would require a vehicle with different axle configuration. In other words, the more axles under a vehicle, the less the pavement damage at a given load. Prior to approval of especial permit, transporters should use special vehicle that would minimize the impact of truck overloads on the road infrastructures.

**(iv) Truck weight optimization software or sensors**

A legal gross load could be overloaded on some axles and under loaded on other axles. This requires selecting appropriate loading pattern. Truck loading software are available in mobile applications which can help drivers and vehicle operators to optimize their vehicular gross load to the maximum permissible limit. Load sensors could also be installed in individual axles to provide accurate real time data to the driver.

For example heavy vehicles with axle configuration 1.2 (one two wheel front axle and one four wheel rear axle) were given special permit to be evaluated based on gross vehicle weight and not axle weight. As a result vehicles with overload up to 16ton per axle, which is 60% beyond the legal axle load limit of 10 ton were allowed to use the road. This is gravely wrong since it is the axle loads that damage the road pavement, the axle load limit should prevail. Instead of giving special permit to such vehicles, it is recommended that such vehicles load only to legal axle load limit or be replaced with heavy vehicles with 3 or more axles.

**(v) Data bank**

The major challenge in conducting this research was the lack of properly organized data. Road networks, pavement performances, traffic, vehicle operating costs; travel time costs, etc should be collected and stored for future studies and decision making purposes. This is specially advised to the Ethiopian Toll Road Enterprise and ERA. Generally, treatment intervention criteria and maintenance standards should be developed using field studies conducted on some selected sections. However, derived treatment intervention criteria and roads economic analysis in general is based on HDM-4 analysis. A study need to be conducted in future to check whether these maintenance criteria are consistent with the set of criteria that may be developed from field studies using the Long Term Pavement Performance (LTPP) sections. This requires continuous data recording and management which is major weakness of the road sector in Ethiopia.

## 7. PROPOSED RESEARCH TOPICS

The following research areas are proposed for future study:

- **Overload Fine Structure for National Road Network**

This basically requires scaling up and including other costs, which were not considered in this study and determine overload fine structure in Ethiopia. Due to time and budget limitation, only the Addis Adama Road network was considered for overload fine analysis in this Study. Future studies could determine overload fine structures based on wider road major network in Ethiopia. Impact of overloaded trucks on bridge structures and impact on safety should also be considered.

- **Optimum Maintenance Standards for National Road Network**

There were no optimized maintenance standards (maintenance type and trigger values), for major road networks in Ethiopia. Therefore, a study needs to be conducted to determine optimal maintenance standards of major road network in Ethiopia.

- **HDM-4 Calibration**

In this study, higher level calibration of HDM 4 road deterioration models was not performed as it requires monitoring the actual progress of different deterioration parameters of road network for some years. After the pavement has been constructed, information on performance, such as distress, roughness, traffic loading, skid characteristic, deflection etc., should be monitored and put into a data bank. The data bank indicates how well past estimates of HDM-4 have matched observed values and can be used to calibrate HDM-4 for better future estimates.

- **Truck size, axle load and gross vehicle weight regulation and harmonization.**

Different regional countries in Africa have different axle load limits. A legal axle load or gross vehicle weight in one country could be illegal in some other country. This creates logistics barrier which hinders trade and partnership between neighbouring countries. Hence, analysis need to be performed considering wider road network of regional countries and harmonized axle load limits along with recommendations could be forwarded

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**APPENDIX**

**APPENDIX A**

Axle Load Data Survey Format

Number	Axle Distribution of Vehicles								Vehicle Type
	F1	F2	R1	R2	R3	R4	R5	R6	
1									
2									
.									

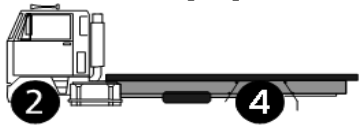
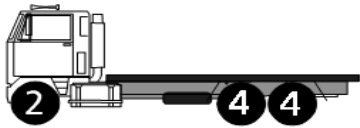
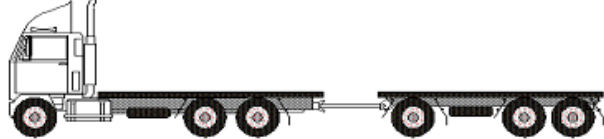
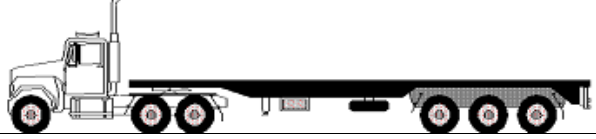

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Date: \_\_\_\_\_

Signature: \_\_\_\_\_

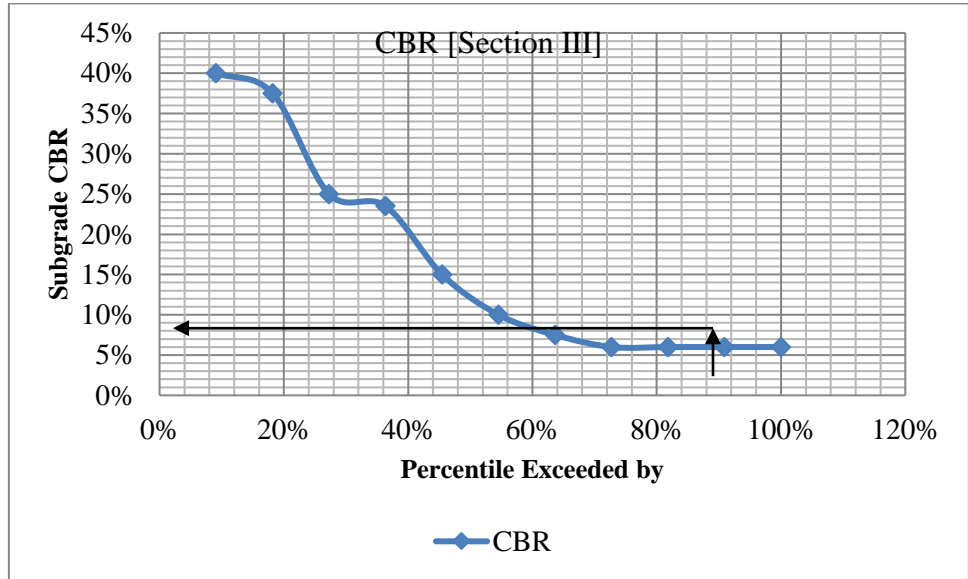
Notation of Axle Configuration and Vehicle Types

Vehicle Category	Description	Vehicle Type
Heavy Vehicles	Large two axle truck >7.5 ton	2 Axle 6 Wheel [1.2] 
	Heavy Truck [HT] Three axle truck >7.5ton	3 Axle 10 wheel [1.22] 
Truck and Trailers	Truck and Trailer [TT1]	6 Axle 22 wheel [1.22+2.22] 
	Semi Trailer [ST2] 3 Axle on Truck and 3Axle on Trailer	6 axle 22 wheel [1.22-222] 
	Semi Trailer [ST3] 3 axle on truck and 2 Axle on trailer	5 axle 18 wheel [1.22-22] 

## APPENDIX B

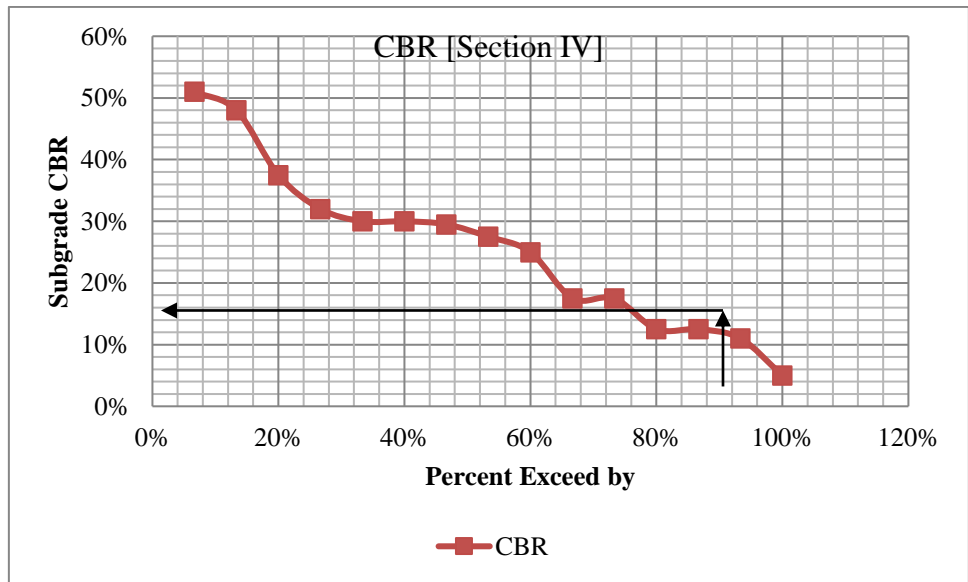
### Subgrade Strength (Design CBR)

Road Section III			Percent Exceeded by
Station (Km)	CBR (%)	CBR (%)	
52	2.5%	6%	100%
53	15.0%	6%	91%
54	2.5%	6%	82%
54.5	10.0%	6%	73%
55	5.0%	8%	64%
55.5	3.0%	10%	55%
57.5	27.5%	15%	45%
58	7.5%	24%	36%
59	40.0%	25%	27%
61	25.0%	38%	18%
63	27.5%	40%	9%



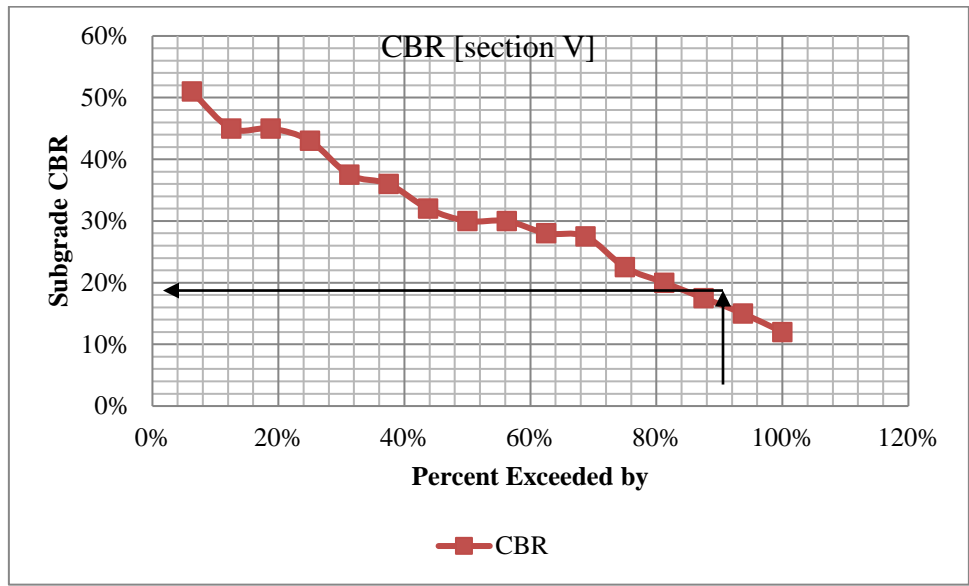
Selected CBR for HDM-4 analysis of Section III CBR=6%

Road Section IV			Percent Exceeded by
Station (Km)	CBR (%)	CBR (%)	
63.5	30.0%	5%	100%
64	29.0%	11%	93%
64.1	6.0%	13%	87%
65	10.0%	13%	80%
66	48.0%	18%	73%
66.1	38.0%	18%	67%
66.5	27.5%	25%	60%
67	12.5%	28%	53%
67.5	17.5%	30%	47%
68	50.0%	30%	40%
68.5	25.0%	30%	33%
69	12.5%	32%	27%
70.5	30.0%	38%	20%
70.6	32.5%	48%	13%
71.5	37.5%	51%	7%



Selected CBR for HDM-4 analysis of Section IV CBR=12%

Road Section V			Percent Exceeded by
Station (Km)	CBR (%)	CBR (%)	
72	45.0%	<b>12%</b>	100%
72.5	20.0%	15%	94%
73	30.0%	<b>18%</b>	<b>88%</b>
73.5	43.0%	20%	81%
73.6	45.0%	23%	75%
74	27.5%	28%	69%
74.1	17.5%	28%	63%
74.5	15.0%	<b>30%</b>	56%
75	25.0%	30%	50%
75.1	22.5%	32%	44%
75.5	12.5%	36%	38%
77.5	30.0%	<b>38%</b>	31%
77.6	50.0%	43%	25%
78	32.5%	45%	19%
78.3	35.0%	45%	13%



Selected CBR for HDM-4 analysis of Section III CBR= 16%

## APPENDIX C

### Vehicle Fleet Characteristics

Vehicle type	Cars	Pick Up	Small Truck	Medium Truck	Heavy Truck	Truck and Trailer
Base Type	Car Medium	Four Wheel Drive	Truck Light	Truck Medium	Truck Heavy	Truck Articulated
Class	Passenger Cars	Utilities	Truck	Truck	Truck	Truck
Description	medium passenger cars (Toyota Corolla)	Land rover /Pajero	small two-axle rigid truck (approx. < 3.5 tones)	medium two-axle rigid truck (> 3.5 tones)	multi-axle rigid truck Camions	Articulated truck or truck with drawbar trailer
<b>Basic Characteristics</b>						
Passenger Car Space Equivalent	1	1	1.3	1.4	1.6	1.8
No. of Wheels	4	4	4	6	10	22
No. of Axles	2	2	2	2	3	6
Tyre Type	Radial ply	Bias ply	Bias ply	Bias Ply	Bias-ply	Bias-ply
Base No. of recaps	1.3	1.3	1.3	2.4	2.4	3.6
Retreated cost	15%	15%	15%	15%	15	15%
Annual km	20000	36000	48000	54000	63000	63000
Working hours	500	1050	1600	1800	2000	2000
<b>Average Life</b>	<b>12</b>	<b>12</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>14</b>
Private use	100%	15%	0	0	0	0
Passengers	3	3	1	1	0	0
Passengers used	2	2				
Work Related Trips	75%	85%	100%	100%	100%	100%
<b>ESALF</b>	<b>0.001</b>	<b>0.01</b>	<b>0.14</b>	<b>0.5.72</b>	<b>9.36</b>	<b>11.5</b>
<b>Operating Weight</b>	<b>1.2</b>	<b>1.5</b>	<b>3</b>	<b>20</b>	<b>30</b>	<b>45</b>

<b>Economic Unit Cost</b>						
New vehicle	275,628.60	699,579.90	1,431,396.90	1,843,822.80	2,829,060.90	3,977,584.20
Replacement tyre	1,200.00	3,000.00	4,500.00	6,300.00	7,650.00	9,000.00
Fuel	19.68	19.68	19.68	19.68	19.68	19.68
Lubricating Oil	45.5	45.5	45.5	45.5	45.5	45.5
Maintenance labour	10.25	16.195	16.195	16.195	16.195	16.195
Crew wages	10.25	10.25	25.42	25.01	28.085	35.67
Annual overhead	3690	4768.3	23841.5	23841.5	95345.5	143028.5
Annual interest	11%	11%	11%	11%	11%	11%
Passenger working time	15.375	9.225	11.275	11.275	11.275	11.275
Passenger non-working time	1.23	1.23	0.82	0.82	0.82	0.82
Cargo	0	0	2.46	3.075	7.5	10
<b>Financial Cost</b>						
New vehicle	306,254.00	777,311.00	1,590,441.00	2,048,692.00	3,143,401.00	4,419,538.00
Replacement tyre	1,200.00	3,000.00	5,000.00	7,000.00	8,500.00	10,000.00
Fuel	22.63	22.63	22.63	22.63	22.63	S
Lubricating Oil	52.33	52.33	52.33	52.33	52.33	52.33
Maintenance labour	11.79	18.62	18.62	18.62	18.62	18.62
Crew wages	11.79	11.79	29.23	28.76	32.30	41.02
Annual overhead	4,243.50	5,483.55	27,417.73	27,417.73	109,647.33	164,482.78
Annual interest	0.13	0.13	0.13	0.13	0.13	0.13
Passenger working time	17.68	10.61	12.97	12.97	12.97	12.97
Passenger non-working time	1.41	1.41	0.94	0.94	0.94	0.94
Cargo	-	-	2.83	3.54	8.63	11.50

## APPENDIX D1

Traffic Mix With and Without Overloading of Five road Sections and in two directions

Road section; Addis Ababa - Debre Zeit		[Up Hill]						[Down Hill]					
User Category	Vehicle Type	Estimated 2014 AADT for Overload Case						Estimated 2014 AADT for Overload Case					
		Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
User Class I (UC1)	Car	705	705	705	705	705	705	609	609	609	609	609	609
	4WD	702	702	702	702	702	702	607	607	607	607	607	607
User Class III (UC3)	Small Truck	604	604	604	604	604	604	524	524	524	524	524	524
	Medium Truck	150	150	150	150	150	150	130	130	130	130	130	130
	Heavy Truck	309	222	222	222	222	222	268	193	193	193	193	193
	Overloaded Heavy Truck 1		45	45	45	45	45		39	39	39	39	39
	Overloaded Heavy Truck 2			21	21	21	21		18	18	18	18	18
	Overloaded Heavy Truck 3				14	14	14				12	12	12
	Overloaded Heavy Truck 4					3	3					3	3
	Overloaded Heavy Truck 5						2						2
	Legalized Heavy Truck		41	20	7	3	1		36	18	6	3	1
	Ideal Medium Truck			3	2	1	1			3	1	1	1
	Ideal Small Truck		48						42				
	Truck & Trailer	643	354	354	354	354	354	558	307	307	307	307	307
	Overloaded Truck and Trailer 1		82	82	82	82	82		71	71	71	71	71
	Overloaded Truck and Trailer 2			120	120	120	120			104	104	104	104
	Overloaded Truck and Trailer 3				61	61	61				53	53	53
	Overloaded Truck and Trailer 4					15	15					13	13
	Overloaded Truck and Trailer 5						8						7
Legalized Truck and Trailer		207	87	27	12	4		180	76	23	10	4	
Ideal Medium Truck		84	33	11	4	0		73	28	9	4	0	
Total		3112	3244	3148	3125	3117	3113	2696	2811	2727	2706	2701	2697

Road section; Debre Zeit - Modjo		[Up Hill]						[Down Hill]					
User Category	Vehicle Type	Estimated 2014 AADT for Overload Case						Estimated 2014 AADT for Overload Case					
		Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
User Class I (UC1)	Car	467	467	467	467	467	467	449	449	449	449	449	449
	4WD	667	667	667	667	667	667	641	641	641	641	641	641
User Class III (UC3)	Small Truck	722	722	722	722	722	722	584	584	584	584	584	584
	Medium Truck	111	111	111	111	111	111	89	89	89	89	89	89
	Heavy Truck	199	143	143	143	143	143	161	116	116	116	116	116
	Overloaded Heavy Truck 1		29	29	29	29	29		24	24	24	24	24
	Overloaded Heavy Truck 2			13	13	13	13			11	11	11	11
	Overloaded Heavy Truck 3				9	9	9				7	7	7
	Overloaded Heavy Truck 4					2	2					2	2
	Overloaded Heavy Truck 5						1						1
	Legalized Heavy Truck		26	13	4	2	1		21	11	3	2	1
	Ideal Medium Truck			2	1	1	1			2	1	1	1
	Ideal Small Truck		31						25				
	Truck & Trailer	981	540	540	540	540	540	794	437	437	437	437	437
	Overloaded Truck and Trailer 1		125	125	125	125	125		101	101	101	101	101
	Overloaded Truck and Trailer 2			183	183	183	183			148	148	148	148
	Overloaded Truck and Trailer 3				93	93	93				75	75	75
	Overloaded Truck and Trailer 4					23	23					18	18
	Overloaded Truck and Trailer 5						11						9
Legalized Truck and Trailer		317	133	41	18	7		256	108	33	15	5	
Ideal Medium Truck		129	50	16	6	0		104	40	13	5	0	
Total		3147	3307	3199	3164	3154	3148	2718	2847	2760	2732	2724	2719

Road section; Modjo - Adama West		[Up Hill]						[Down Hill]					
User Category	Vehicle Type	Estimated 2014 AADT for Overload Case						Estimated 2014 AADT for Overload Case					
		Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
User Class I (UC1)	Car	407	407	407	407	407	407	326	326	326	326	326	326
	4WD	581	581	581	581	581	581	465	465	465	465	465	465
User Class III (UC3)	Small Truck	526	526	526	526	526	526	529	529	529	529	529	529
	Medium Truck	81	81	81	81	81	81	81	81	81	81	81	81
	Heavy Truck	145	104	104	104	104	104	146	105	105	105	105	105
	Overloaded Heavy Truck 1		21	21	21	21	21		21	21	21	21	21
	Overloaded Heavy Truck 2			10	10	10	10			10	10	10	10
	Overloaded Heavy Truck 3				6	6	6				6	6	6
	Overloaded Heavy Truck 4					2	2					2	2
	Overloaded Heavy Truck 5						1						1
	Legalized Heavy Truck		19	10	3	2	1		19	10	3	2	1
	Ideal Medium Truck			1	1	1	1			1	1	1	1
	Ideal Small Truck		23						23				
	Truck & Trailer	715	393	393	393	393	393	720	396	396	396	396	396
	Overloaded Truck and Trailer 1		91	91	91	91	91		92	92	92	92	92
	Overloaded Truck and Trailer 2			134	134	134	134			134	134	134	134
	Overloaded Truck and Trailer 3				68	68	68				68	68	68
	Overloaded Truck and Trailer 4					16	16					17	17
	Overloaded Truck and Trailer 5						8						8
Legalized Truck and Trailer		231	97	30	13	5		232	98	30	13	5	
Ideal Medium Truck		94	36	12	5	0		94	36	12	5	0	
Total		2456	2573	2493	2469	2462	2457	2266	2383	2303	2279	2272	2267

Road section; Adama West - Asela Road		[Up Hill]						[Down Hill]					
User Category	Vehicle Type	Estimated 2014 AADT for Overload Case						Estimated 2014 AADT for Overload Case					
		Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
User Class I (UC1)	Car	120	120	120	120	120	120	394	394	394	394	394	394
	4WD	172	172	172	172	172	172	562	562	562	562	562	562
User Class III (UC3)	Small Truck	698	698	698	698	698	698	585	585	585	585	585	585
	Medium Truck	107	107	107	107	107	107	90	90	90	90	90	90
	Heavy Truck	193	139	139	139	139	139	161	116	116	116	116	116
	Overloaded Heavy Truck 1		28	28	28	28	28		24	24	24	24	24
	Overloaded Heavy Truck 2			13	13	13	13			11	11	11	11
	Overloaded Heavy Truck 3				8	8	8				7	7	7
	Overloaded Heavy Truck 4					2	2					2	2
	Overloaded Heavy Truck 5						1						1
	Legalized Heavy Truck		26	13	4	2	1		21	11	3	2	1
	Ideal Medium Truck			2	1	1	1			2	1	1	1
	Ideal Small Truck		30						25				
	Truck & Trailer	949	522	522	522	522	522	795	437	437	437	437	437
	Overloaded Truck and Trailer 1		121	121	121	121	121		101	101	101	101	101
	Overloaded Truck and Trailer 2			177	177	177	177			148	148	148	148
	Overloaded Truck and Trailer 3				90	90	90				75	75	75
	Overloaded Truck and Trailer 4					22	22					18	18
	Overloaded Truck and Trailer 5						11						9
Legalized Truck and Trailer		306	129	39	18	6		256	108	33	15	5	
Ideal Medium Truck		125	48	16	6	0		104	40	13	5	0	
Total		2239	2394	2289	2256	2246	2241	2586	2715	2628	2600	2592	2587

Road section; Asela Road - Adama		[Up Hill]						[Down Hill]					
User Category	Vehicle Type	Estimated 2014 AADT for Overload Case						Estimated 2014 AADT for Overload Case					
		Case 0	Case 1	Case 2	Case 3	Case 4	Case 5	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
User Class I (UC1)	Car	33	33	33	33	33	33	74	74	74	74	74	74
	4WD	47	47	47	47	47	47	106	106	106	106	106	106
User Class III (UC3)	Small Truck	242	242	242	242	242	242	242	242	242	242	242	242
	Medium Truck	37	37	37	37	37	37	37	37	37	37	37	37
	Heavy Truck	67	48	48	48	48	48	67	48	48	48	48	48
	Overloaded Heavy Truck 1		10	10	10	10	10		10	10	10	10	10
	Overloaded Heavy Truck 2			4	4	4	4			5	5	5	5
	Overloaded Heavy Truck 3				3	3	3				3	3	3
	Overloaded Heavy Truck 4					1	1					1	1
	Overloaded Heavy Truck 5						0						0
	Legalized Heavy Truck		9	4	1	1	0		9	4	1	1	0
	Ideal Medium Truck			1	1	1	1			1	1	1	1
	Ideal Small Truck		10						10				
	Truck & Trailer	329	181	181	181	181	181	329	181	181	181	181	181
	Overloaded Truck and Trailer 1		42	42	42	42	42		42	42	42	42	42
	Overloaded Truck and Trailer 2			61	61	61	61			61	61	61	61
	Overloaded Truck and Trailer 3				31	31	31				31	31	31
	Overloaded Truck and Trailer 4					8	8					8	8
	Overloaded Truck and Trailer 5						4						4
Legalized Truck and Trailer		106	45	14	6	2		106	45	14	6	2	
Ideal Medium Truck		43	17	5	2	0		43	17	5	2	0	
Total		754	807	772	760	757	756	854	907	872	860	857	855

## APPENDIX D2

Vehicle Fleet (VAA-AD-EW) and Types vehicles considered for each Overload case

Vehicle Fleet: VAAADEW				Overload Case					
Nº	Vehicle Type	ESALF	GVW (ton)	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
1	Car	0.001	1.2	√	√	√	√	√	√
2	Four Wheel Drive	0.010	1.5	√	√	√	√	√	√
3	Small Truck	0.140	3.0	√	√	√	√	√	√
4	Medium Truck	5.720	20.0	√	√	√	√	√	√
5	Heavy Truck	9.340	28.0	√	√	√	√	√	√
6	Heavy Truck 1 [10% overloaded per axle]	9.918	31.0	×	√	√	√	√	√
7	Heavy Truck 2 [20% overloaded per axle]	13.936	33.0	×	×	√	√	√	√
8	Heavy Truck 3 [30% overloaded per axle]	19.313	35.0	×	×	×	√	√	√
9	Heavy Truck 4 [40% overloaded per axle]	26.350	37.0	×	×	×	×	√	√
10	Heavy Truck 5 [50% overloaded per axle]	35.384	39.0	×	×	×	×	×	√
11	Truck and Trailer	11.450	50.0	√	√	√	√	√	√
12	Truck and Trailer 1 [10% overloaded per axle]	22.493	64.0	×	√	√	√	√	√
13	Truck and Trailer 1 [20% overloaded per axle]	32.537	69.0	×	×	√	√	√	√
14	Truck and Trailer 1 [30% overloaded per axle]	45.979	74.0	×	×	×	√	√	√
15	Truck and Trailer 1 [40% overloaded per axle]	63.571	79.0	×	×	×	×	√	√
16	Truck and Trailer 1 [50% overloaded per axle]	86.156	84.0	×	×	×	×	×	√

Note;

√: Truck can use the road and hence is considered in analysis

×: Truck has to unload extra weight to the nearest limit before using the road. And is not considered in analysis

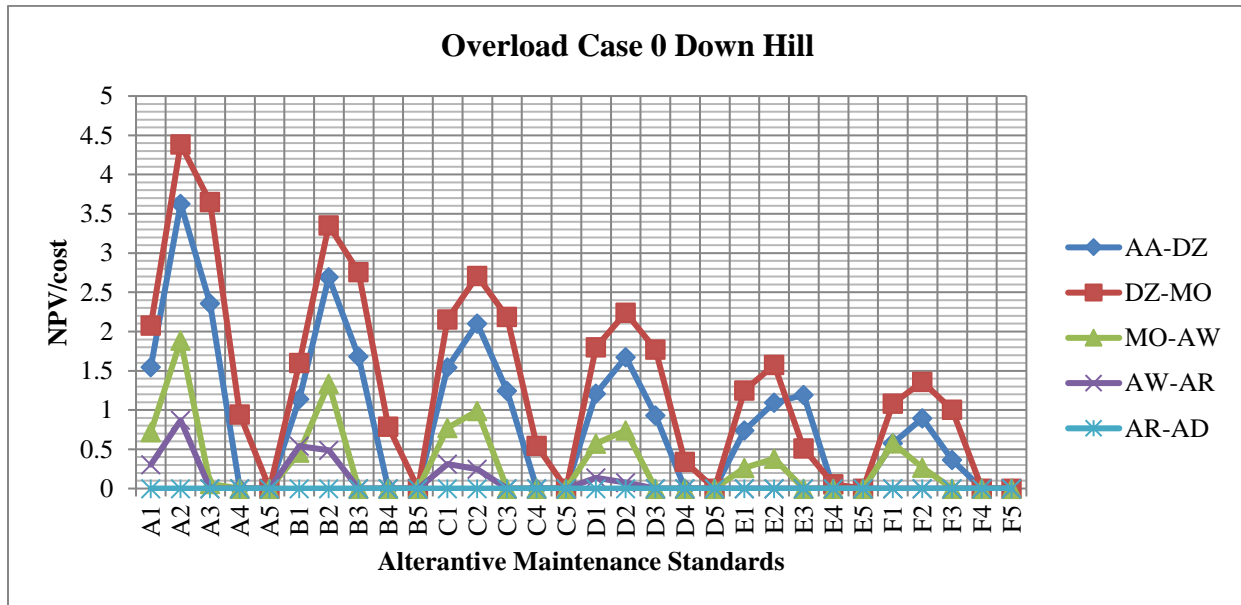
Ideal trucks have truck factor the same as normal truck

Legalized truck have truck factor similar to the maximum value permitted in particular case (Example Truck factor of legalized Heavy vehicles under case 1 is equal to truck factor of Heavy Truck 1, whereas under case 2 is equal to truck factor heavy truck 2 etc.)

## APPENDIX E

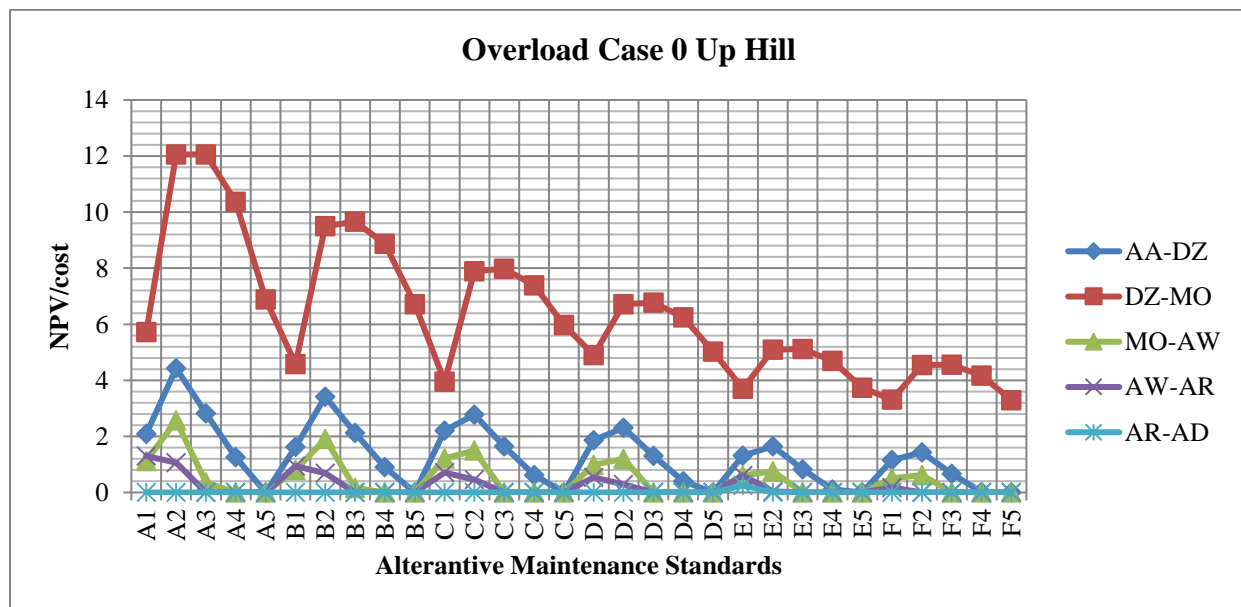
HDM-4 program Analysis Iteration Results of [30 standards X 5 road section X 6 Overload Cases]

NPV/Cost Values of Different Iterations and Primarily Selected Maintenance Alternatives



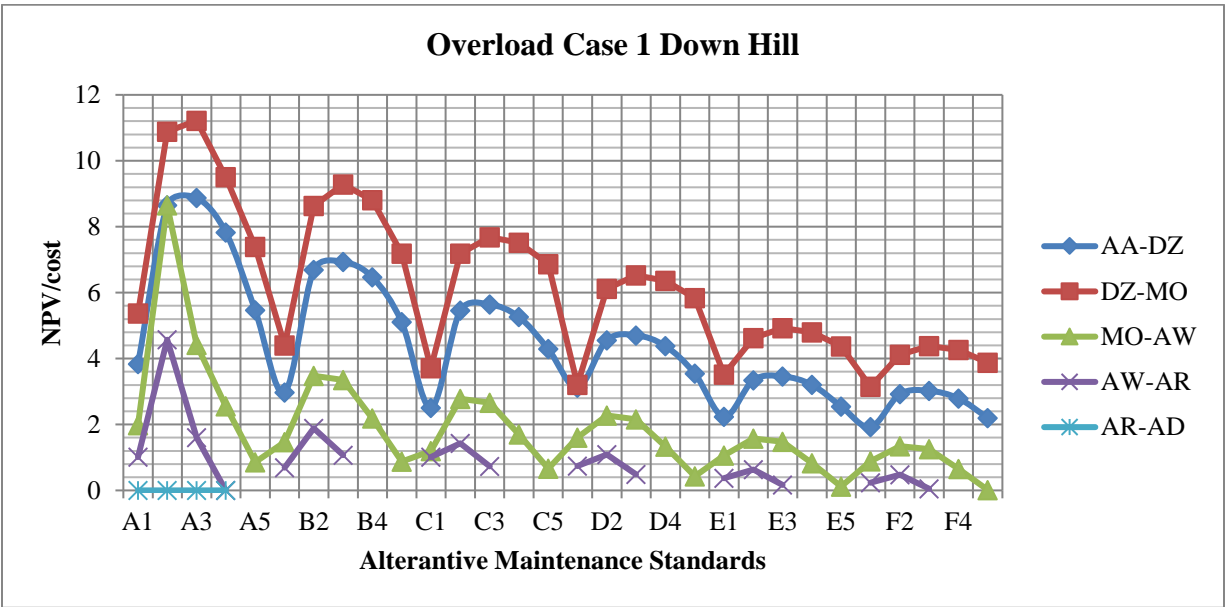
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A2	A2	A2	A2	NR

NR: Not Required



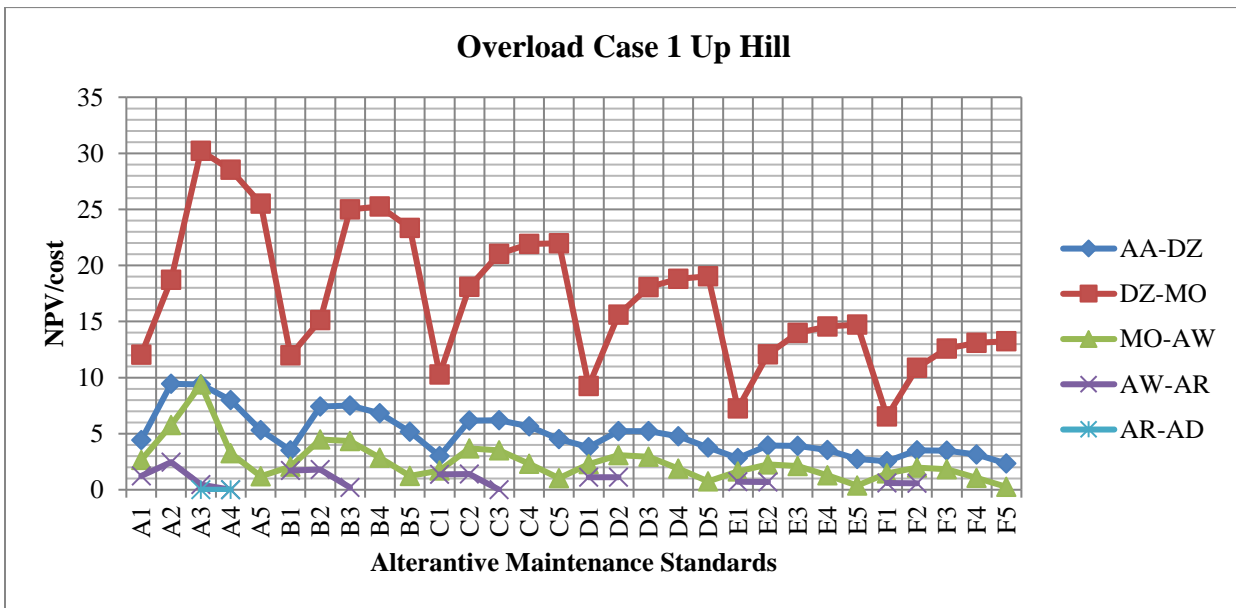
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A2	A3	A2	A2	NR

NR: Not Required



Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	A3	A2	A2	NR

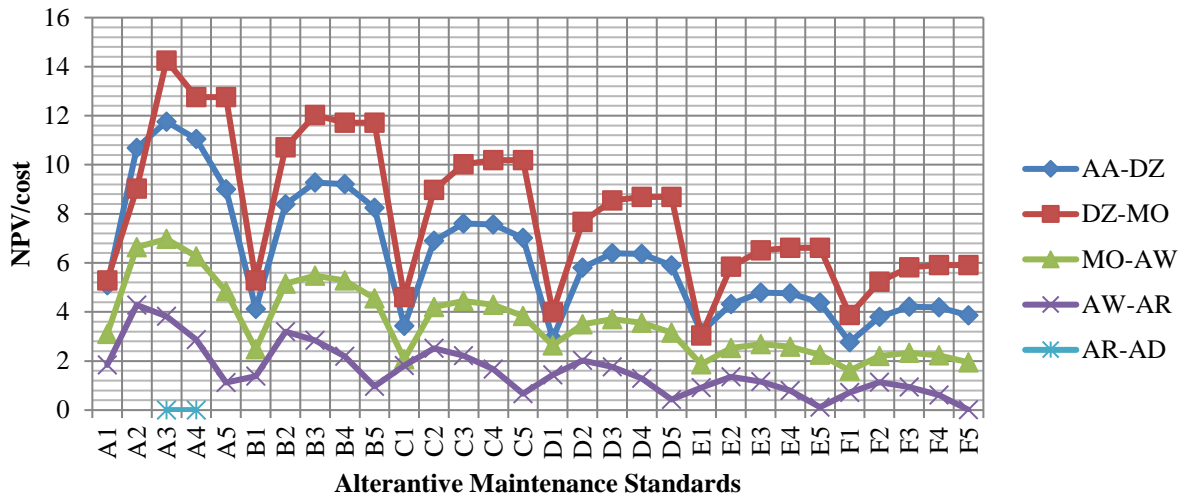
NR: Not Required



Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	A3	A2	A2	NR

NR: Not Required

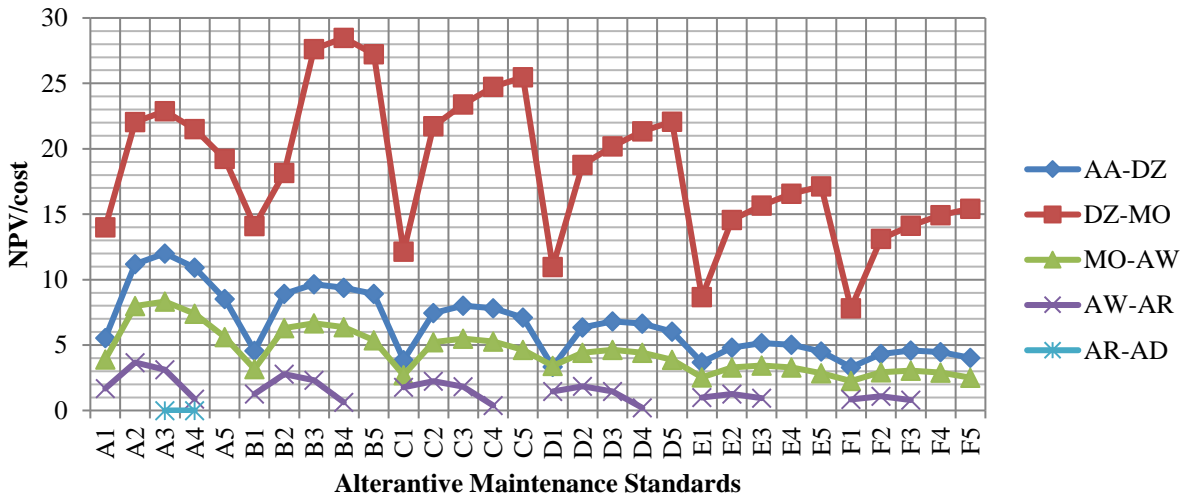
**Overload Case 2 DownHill**



Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	A3	A3	A2	NR

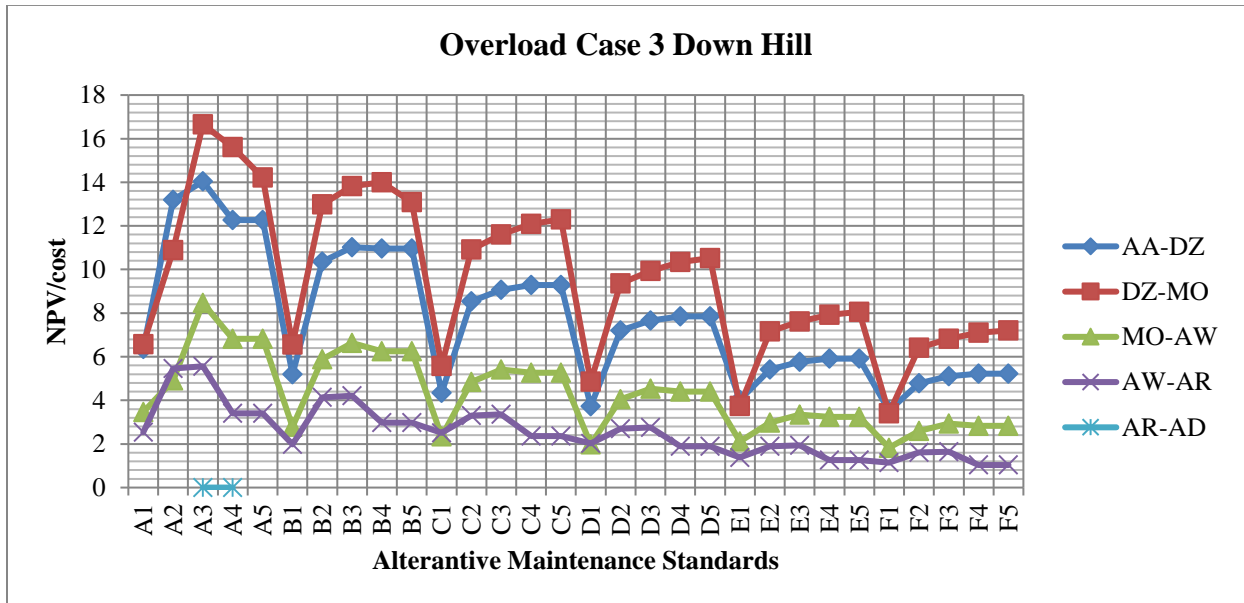
NR: Not Required

**Overload Case 2 Up Hill**



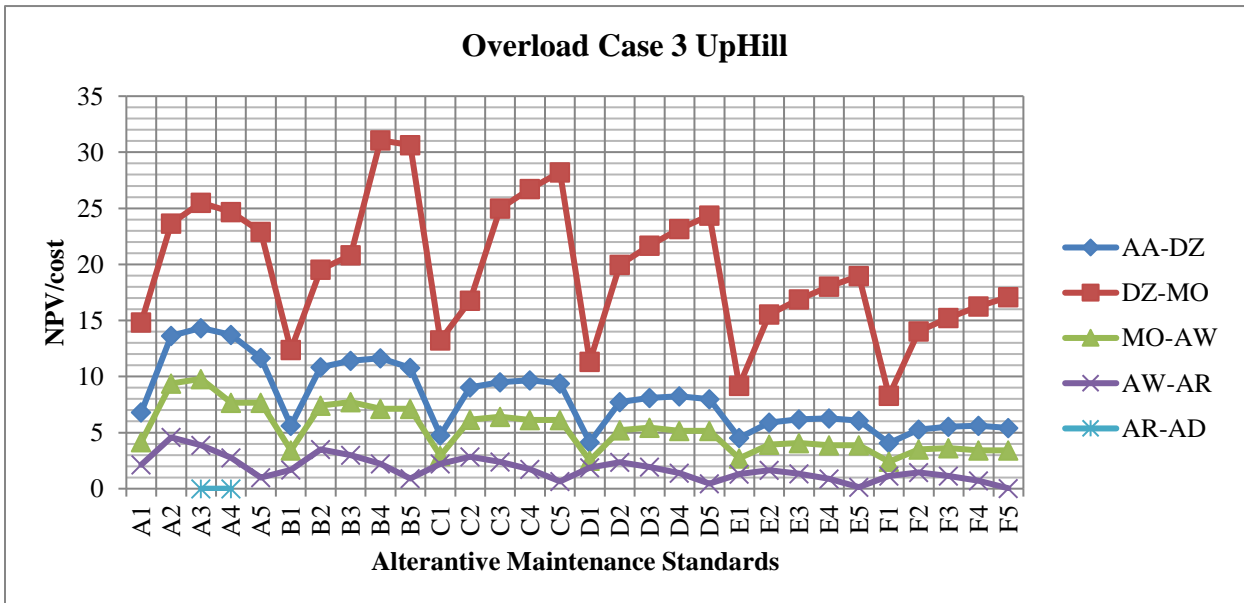
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	B4	A3	A2	NR

NR: Not Required



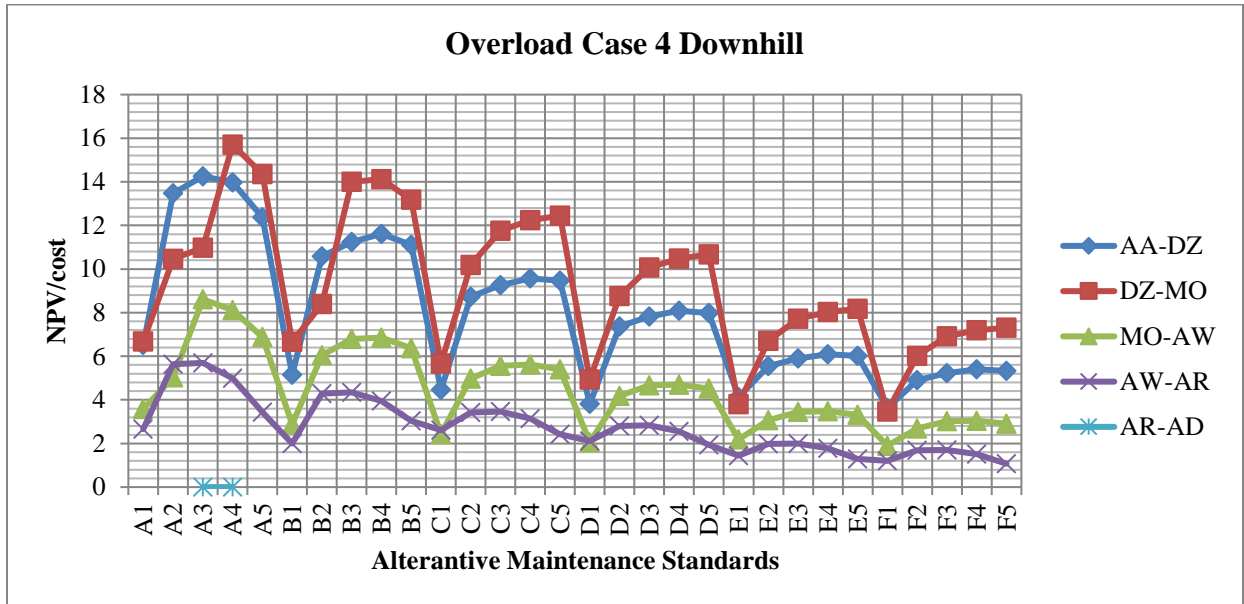
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	A3	A3	A2	NR

NR: Not Required



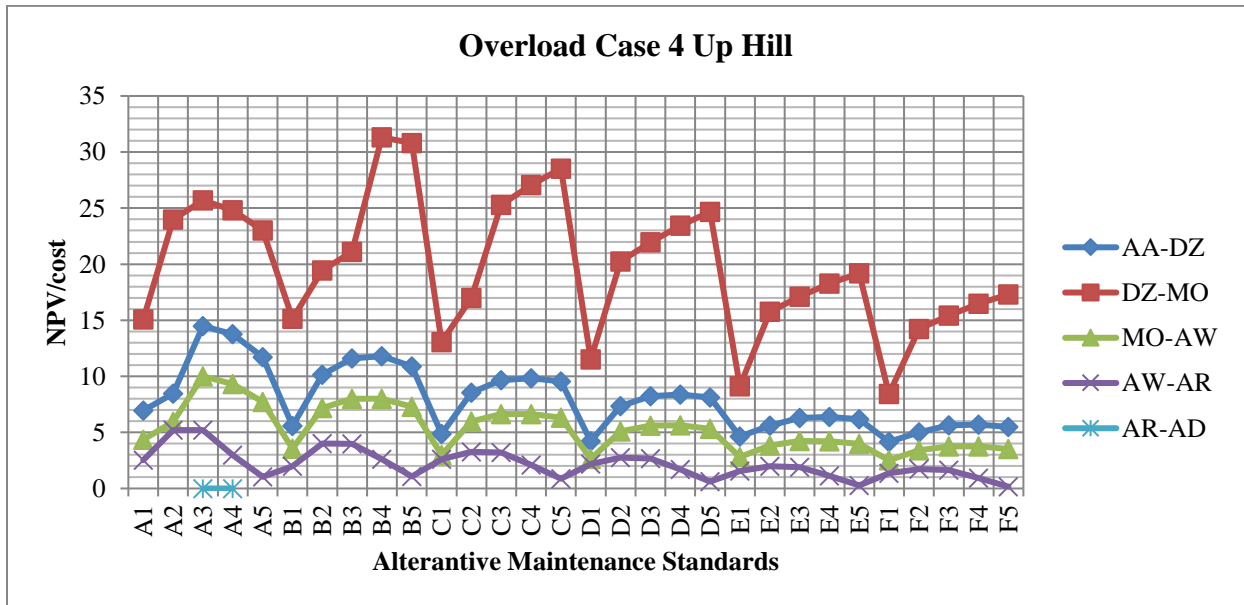
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	B4	A3	A2	NR

NR: Not Required



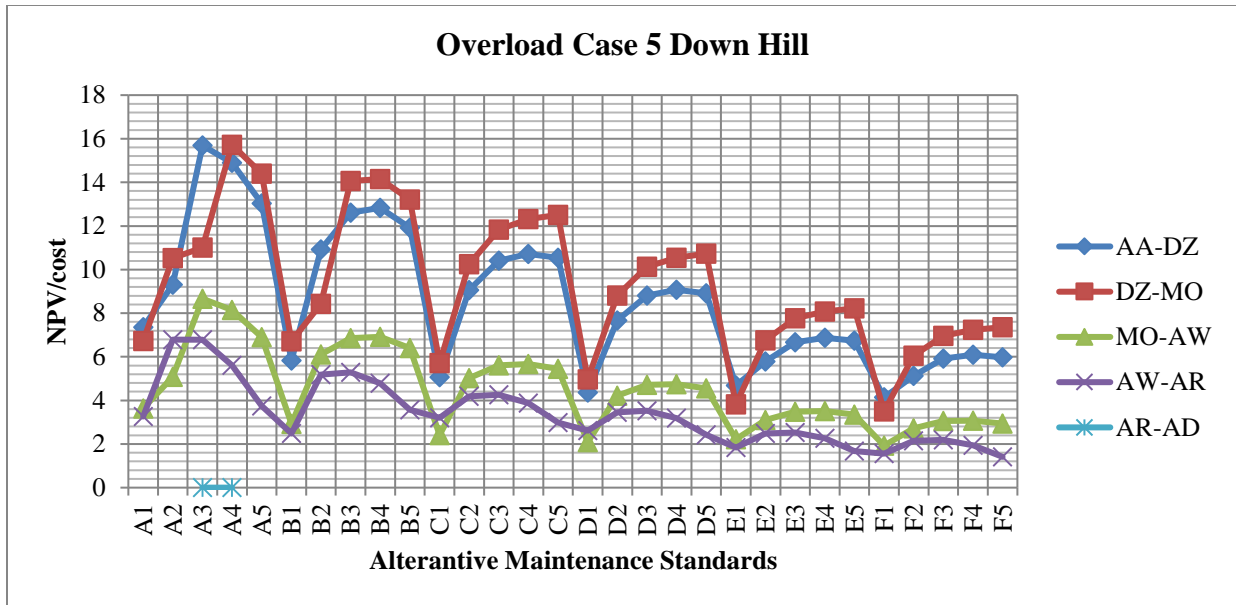
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	A4	A3	A3	NR

NR: Not Required



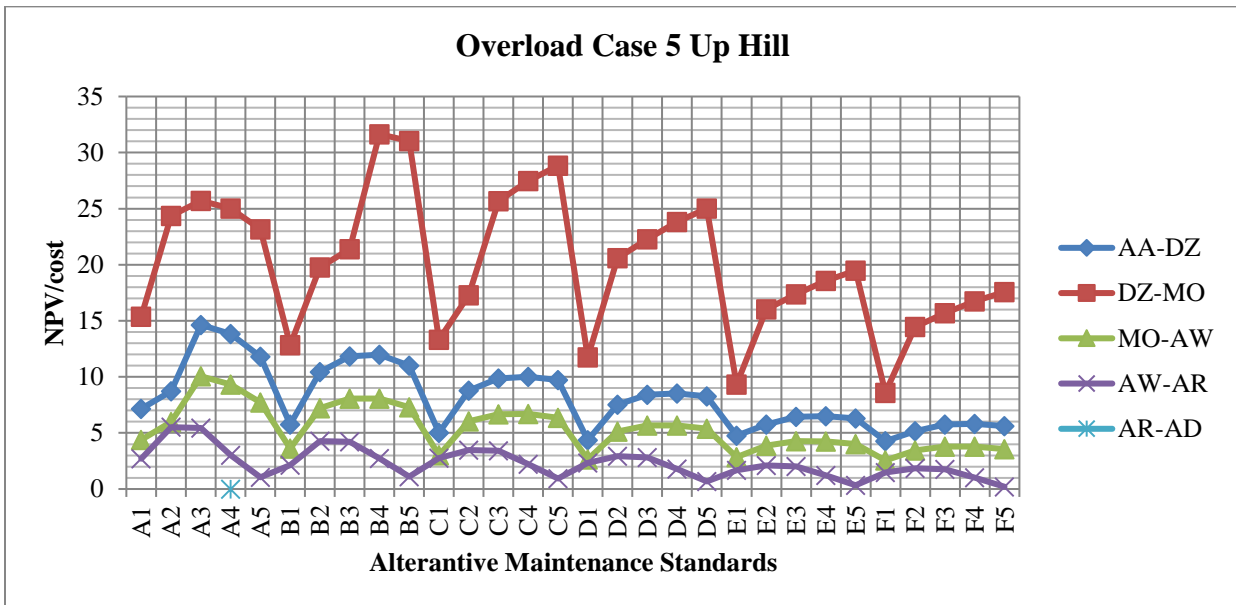
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	B4	A3	A2	NR

NR: Not Required



Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	A4	A3	A2	NR

NR: Not Required



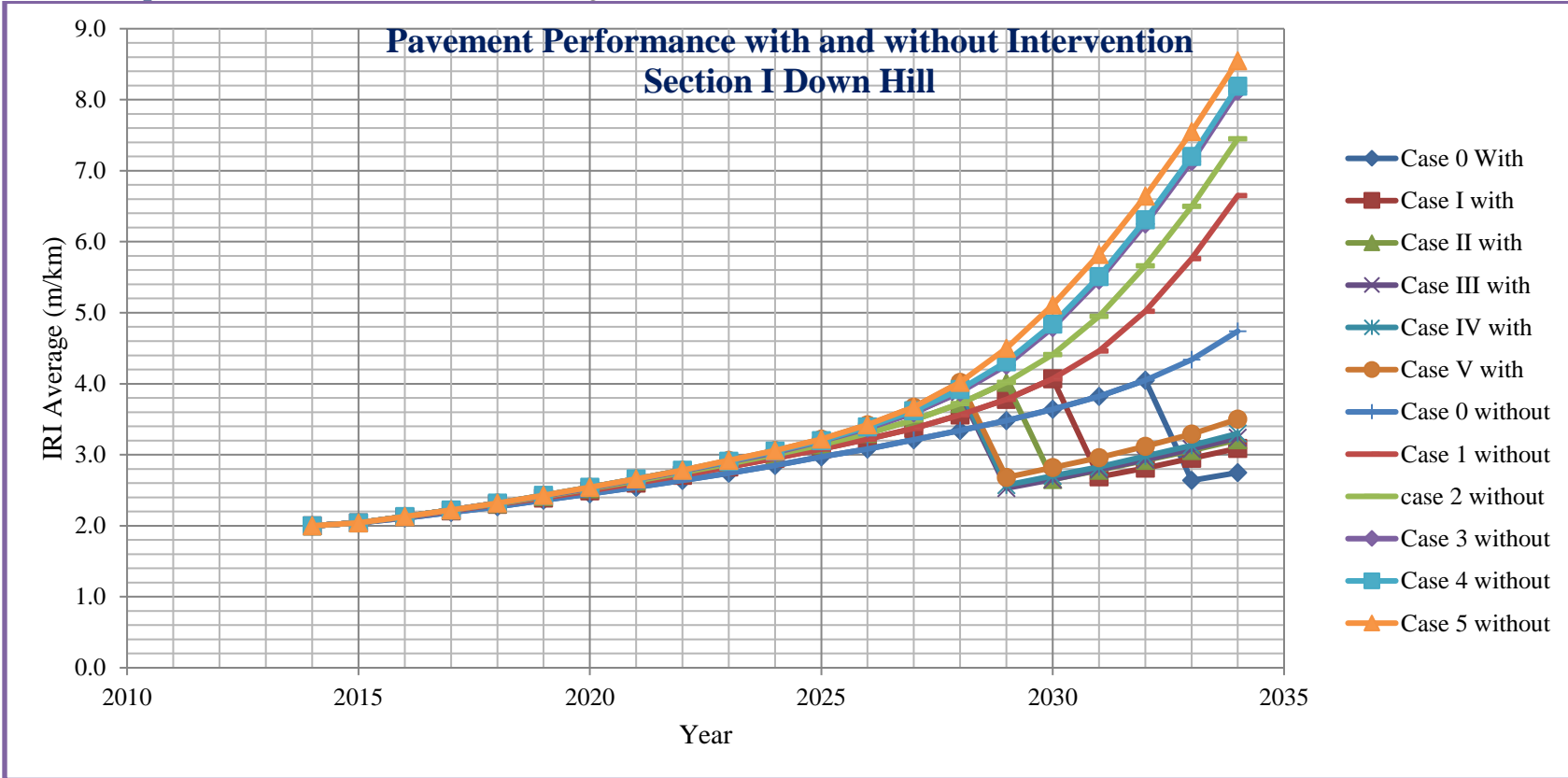
Road Section	AA-DZ	DZ-MO	MO-AW	AW-AR	AR-AD
Selected Intervention	A3	B4	A3	A2	NR

NR: Not Required

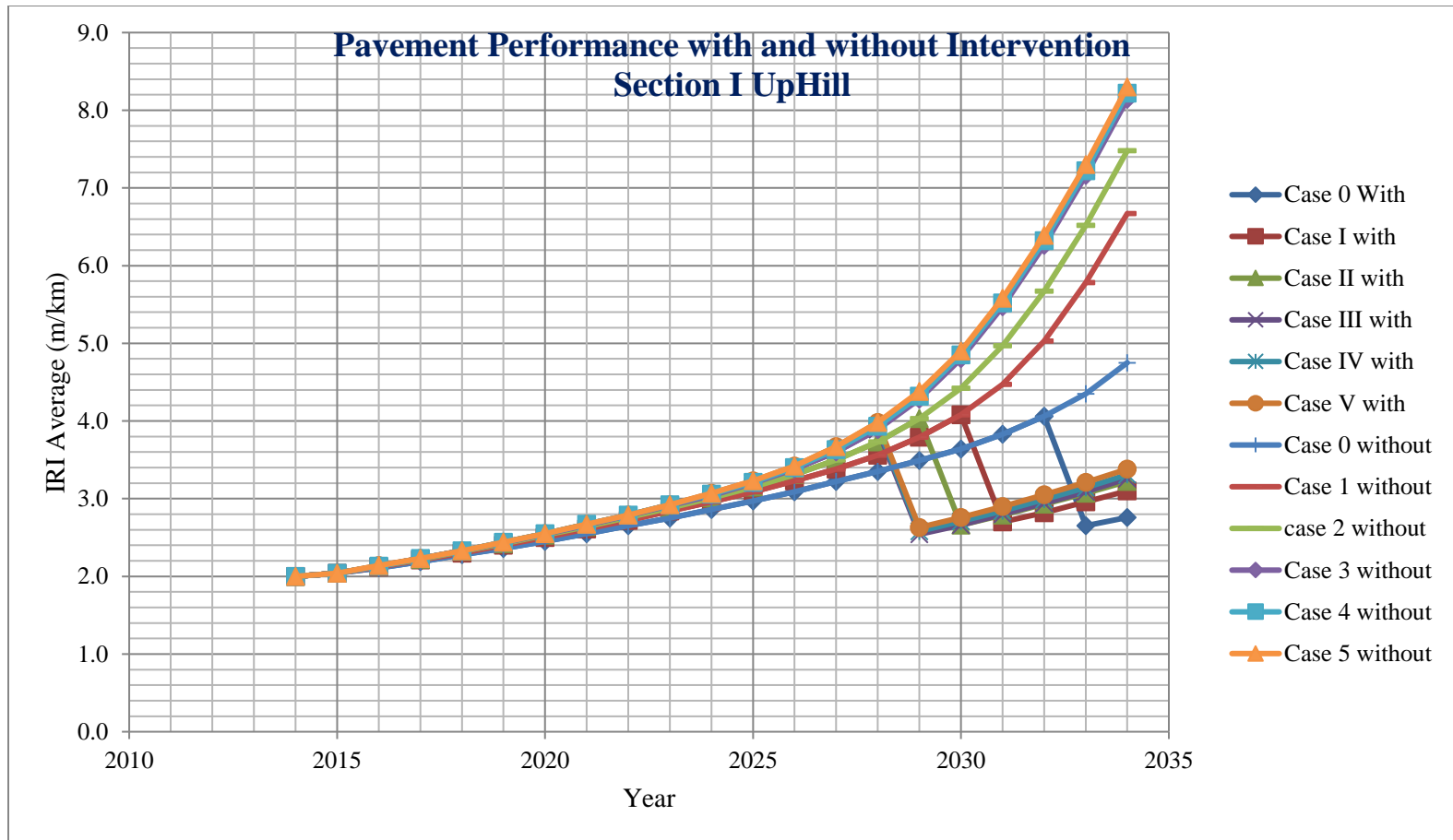
**APPENDIX F**

**HDM 4 Analysis Results [Pavement performance Curves under Each Overloading Cases**

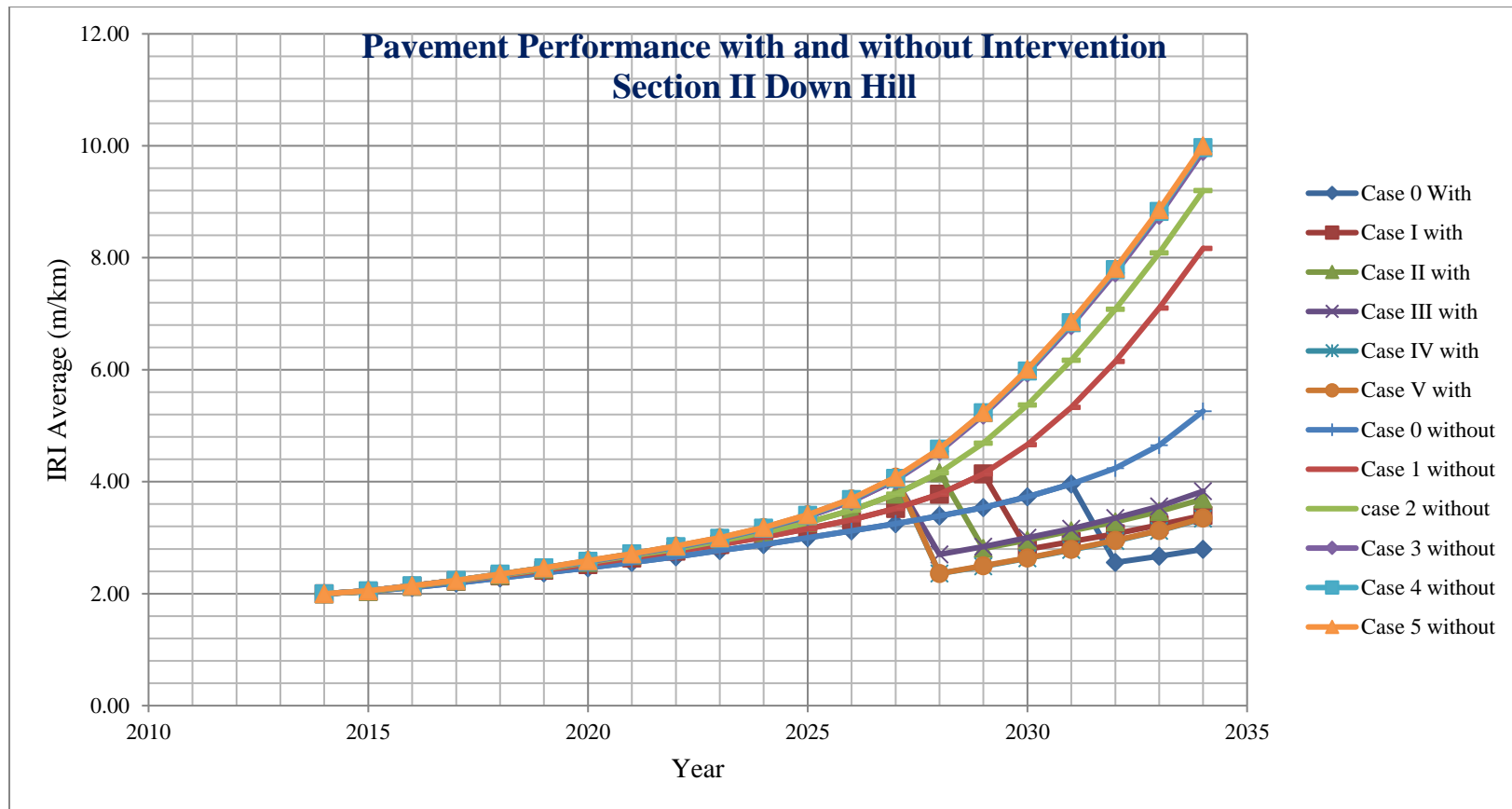
**1. Pavement performance curves of d/t overloading cases under different alternatives for different sections**



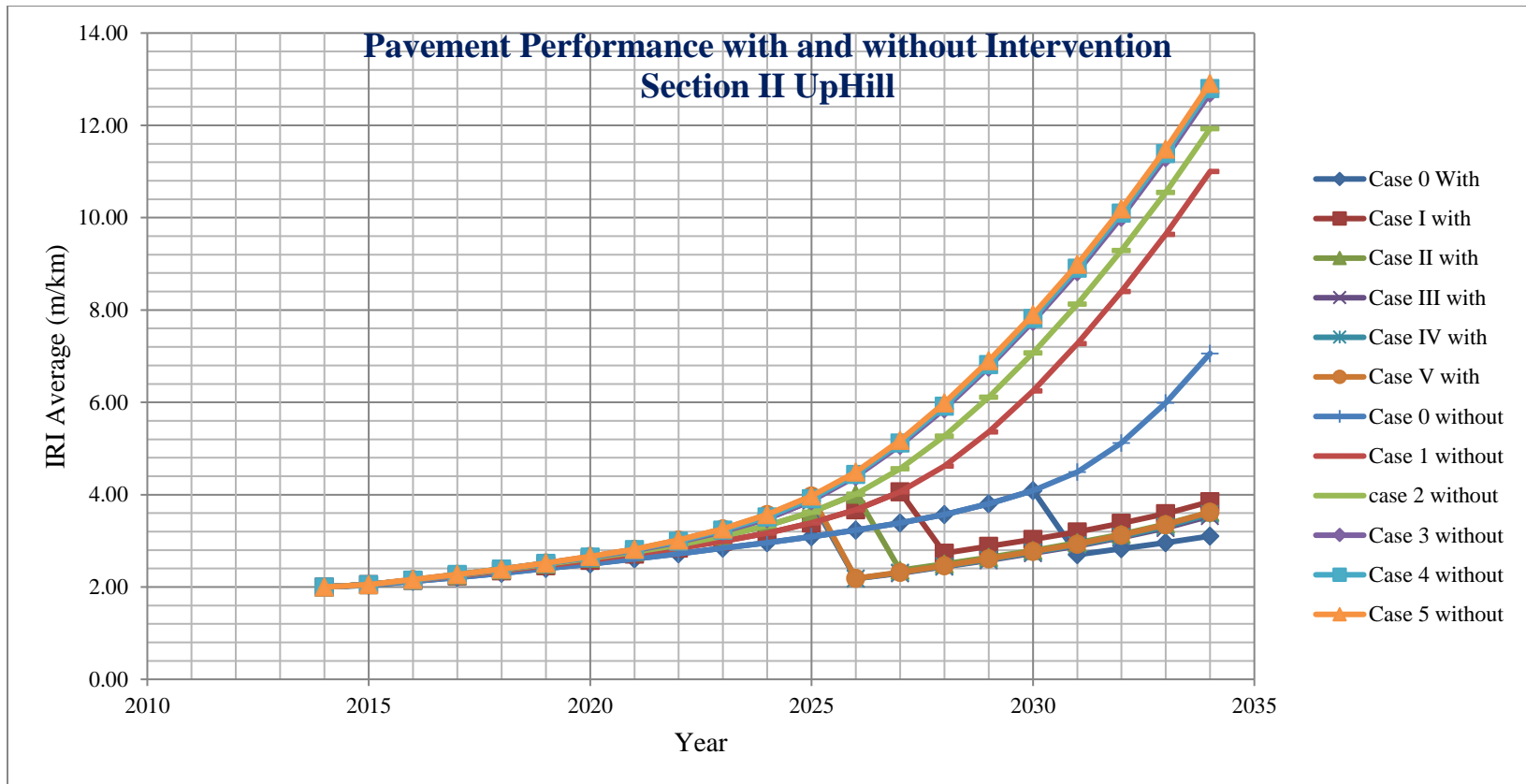
Road Section I [AA-DZ]; Direction Down Hill						
Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Periodic Maintenance	A3 in 2032	A3 in 2030	A3+ Preparatory Patching in 2029	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028, Crack sealing in 2027
<b>Non Pavement Routine Maintenance is required every year</b>			A3 = 30mm Asphalt Concrete Overlay at 4m/km (IRI)			



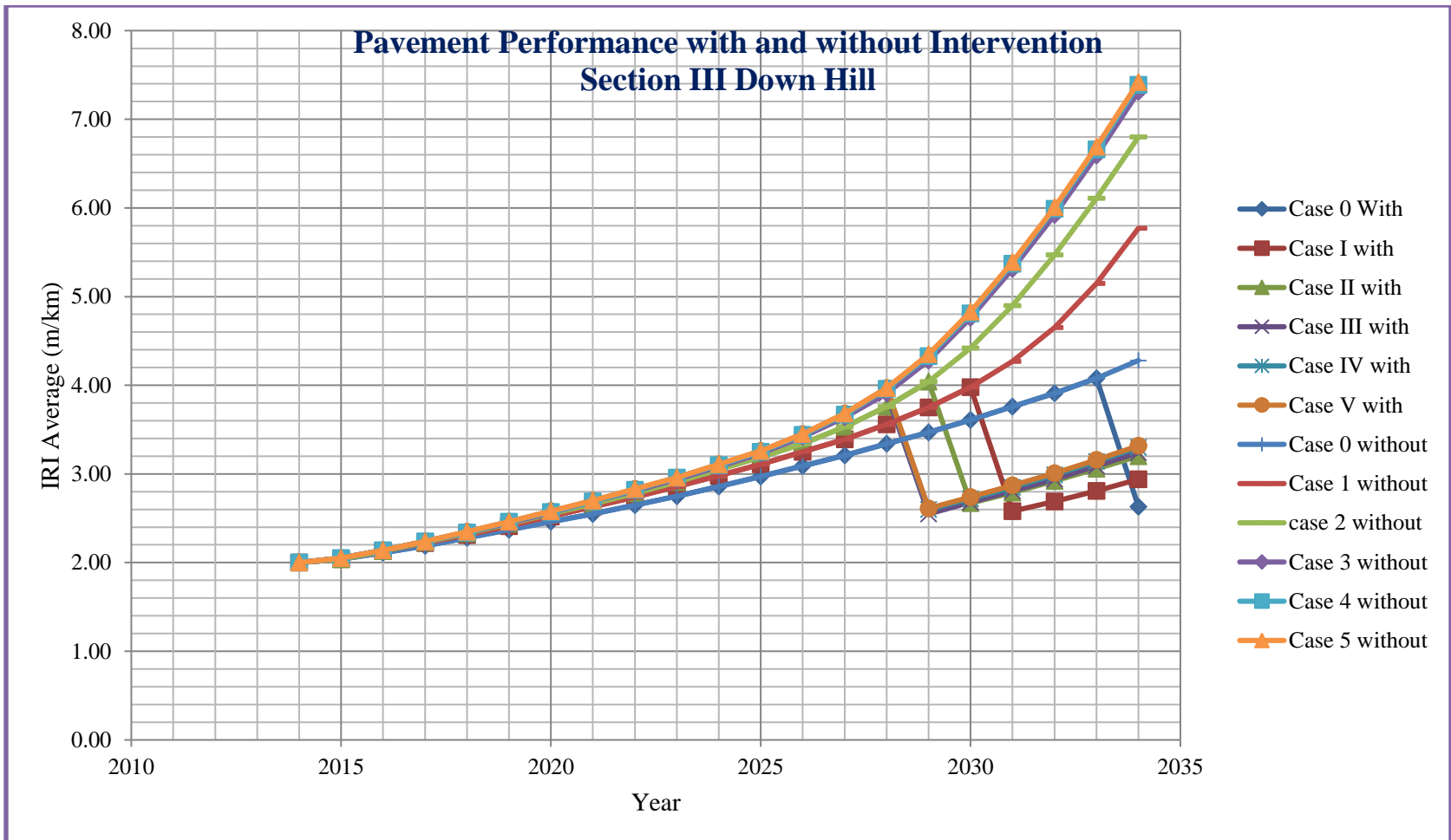
Road Section I [AA-DZ]; Direction Up Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Intervention	A3 in 2032	A3+ Preparatory Patching in 2030	A3+ Preparatory Patching in 2029	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028
<b>Note; A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI)</b>				Non Pavement Routine Maintenance is required every year		



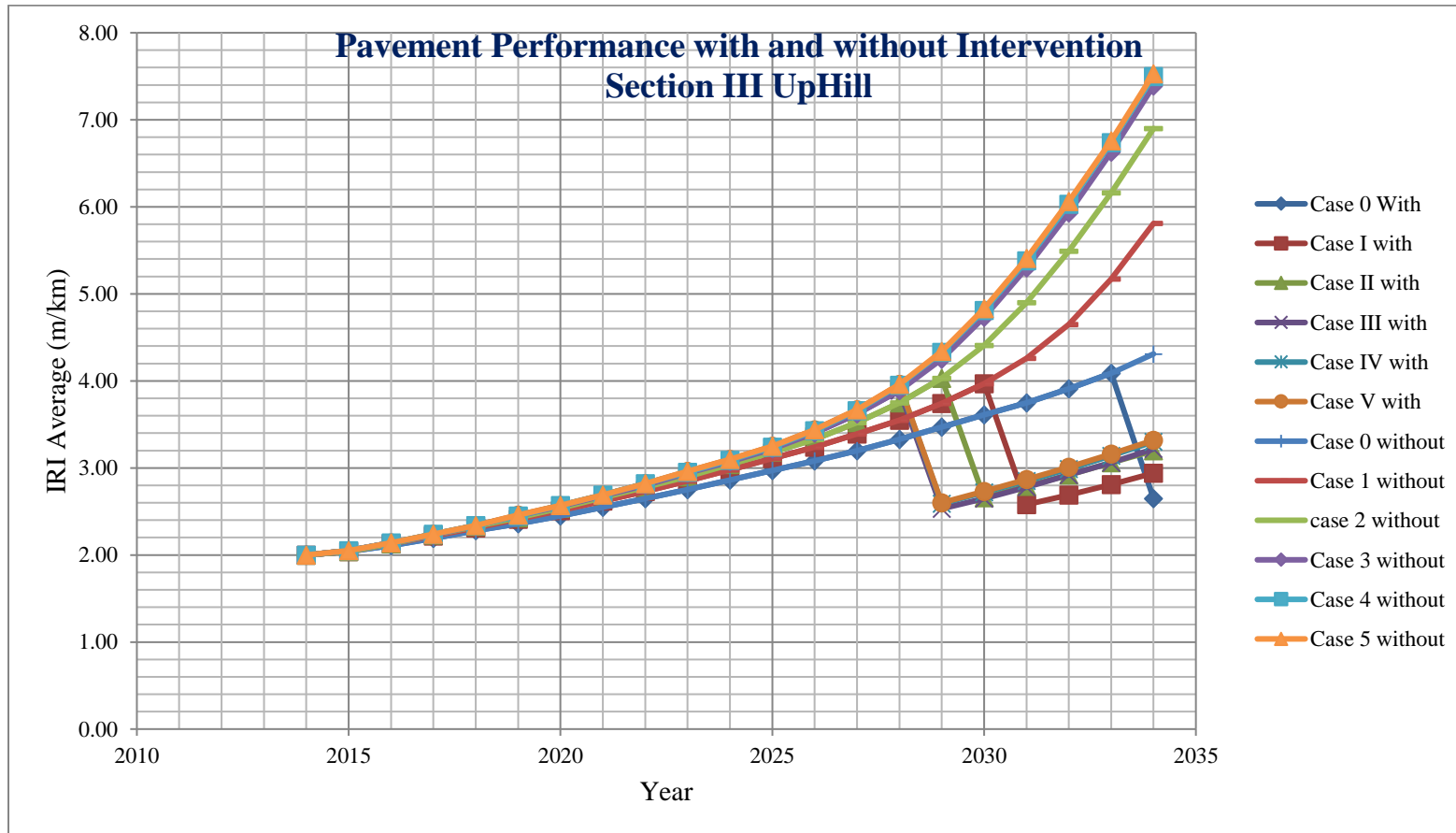
<b>Road Section II [DZ-MO]; Direction Down Hill</b>						
<b>Overload Case</b>	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
<b>Intervention</b>	A3 in 2031	A3 + Preparatory Patching in 2029 , Crack Sealing in 2028	A3+ Preparatory Patching in 2028 , Crack Sealing in 2027	A3 + Preparatory Patching in 2027, Crack Sealing in 2026	B3+ Preparatory Patching in 2027. Crack Sealing in 2026	B3 + Preparatory Patching in 2027, Crack Sealing in 2026
<b>A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI)</b>			<b>B3; 40mm Asphalt Concrete Overlay at 4m/km (IRI)</b> Non Pavement Routine Maintenance is required every year			



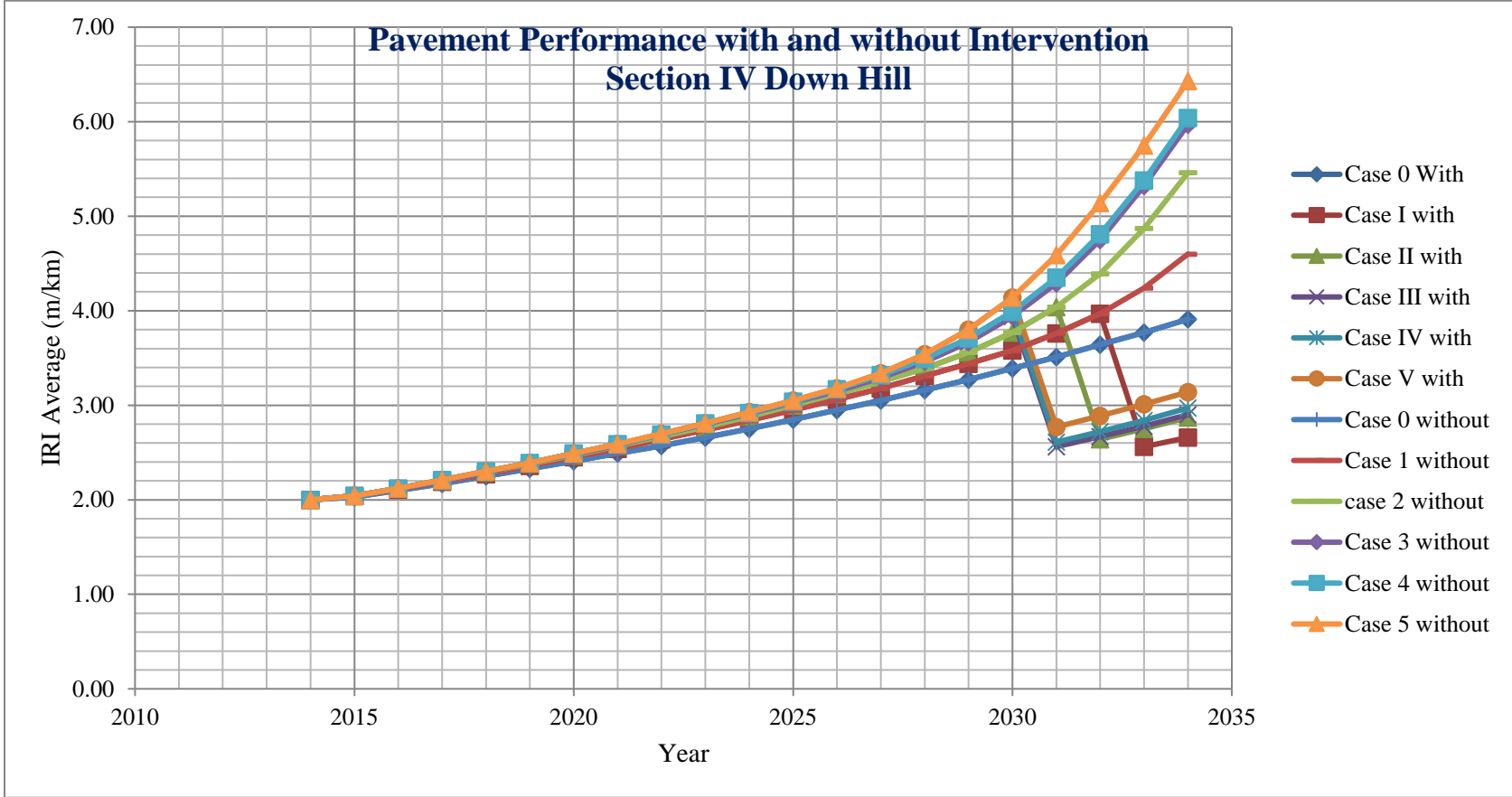
Road Section II [DZ-MO]; Direction Up Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
<b>Intervention</b>	A3 + Preparatory Patching in 2030	A3 + Preparatory Patching in 2027, Crack sealing in 2026	B3 + Preparatory Patching in 2026, Crack Sealing in 2025	C3 + Preparatory Patching in 2025, Crack Sealing in 2024	C3 + Preparatory Patching in 2025, Crack Sealing in 2025	C3 + Preparatory Patching in 2025, Crack Sealing in 2024
<b>Note;</b>	A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI)		B3; 40mm Asphalt Concrete Overlay at 4m/km (IRI)		C3; 50mm Asphalt Concrete Overlay at 4m/km (IRI)	
			Non Pavement Routine Maintenance is required every year			



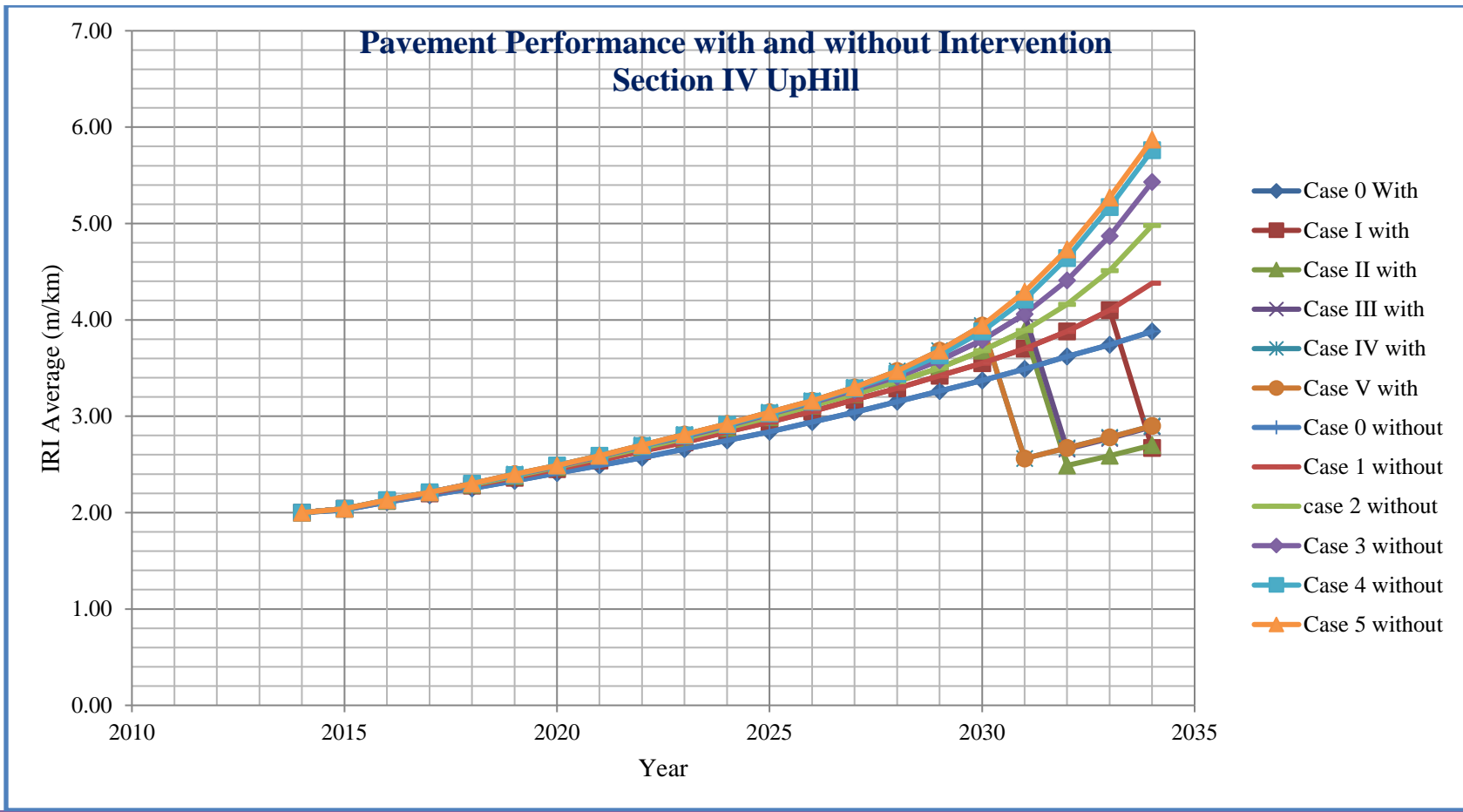
Road Section III [MO-AW]; Direction Down Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
<b>Intervention</b>	A3 in 2033	A3 in 2030	A3+ Preparatory Patching in 2029	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028
<b>A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI); Non Pavement Routine Maintenance is required every year</b>						



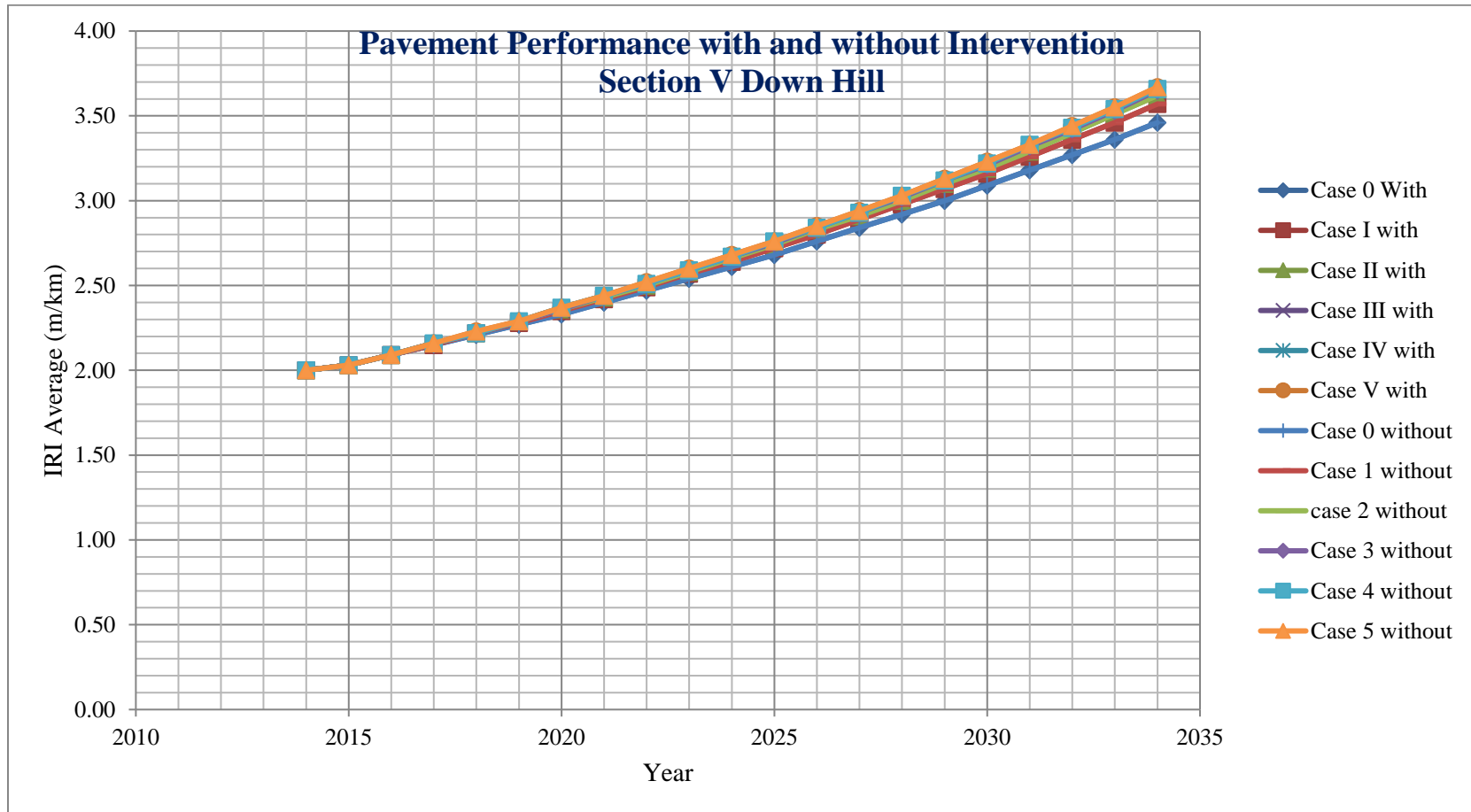
Road Section III [MO-AW]; Direction Up Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Intervention	A3 in 2033	A3 in 2030	A3 + Preparatory Patching in 2029	A3 + Preparatory Patching in 2028	A3 + Preparatory Patching in 2028	A3+Preparatory Patching in 2028
<b>Note; A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI)</b>			Non Pavement Routine Maintenance is required every year			



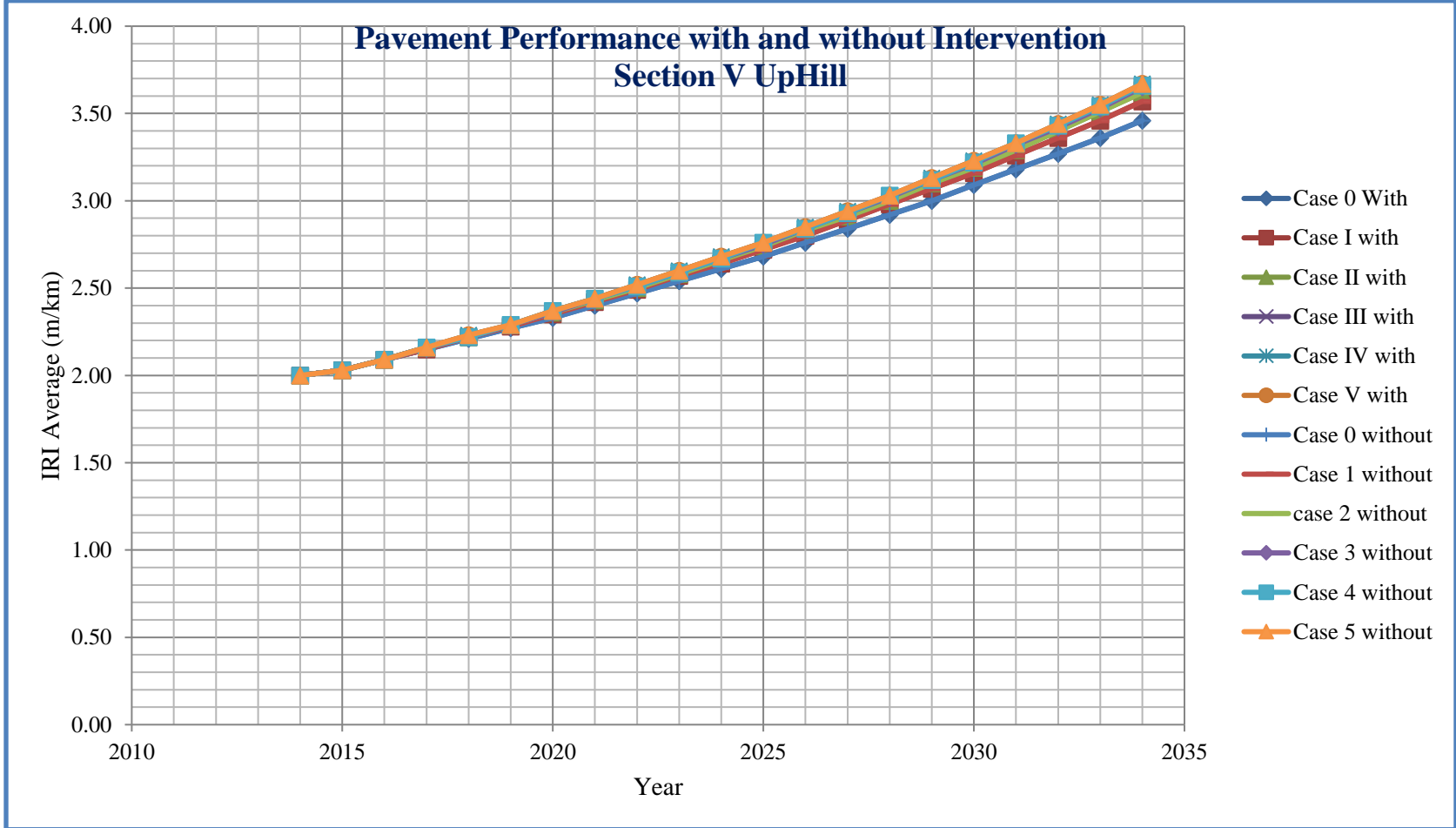
Road Section IV [AW-AR]; Direction Down Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Intervention	No Intervention	A3 in 2032	A3 + Preparatory Patching in 2031	A3 + Preparatory Patching in 2030	A3 + Preparatory Patching in 2030	A3 + Preparatory Patching in 2030, Crack Sealing in 2029
<b>Note; A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI) ; Non Pavement Routine Maintenance is required every year</b>						



Road Section IV [AW-AR]; Direction Up Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Intervention	No Intervention	A3 in 2033	A3 in 2031	A3 + Preparatory Patching in 2031	A3 + Preparatory Patching in 2030	A3+Preparatory Patching in 2030
<b>Note; A3; 30mm Asphalt Concrete Overlay at 4m/km (IRI)</b>			Non Pavement Routine Maintenance is required every year			



Road Section V [AR-AD]; Direction Down Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Intervention	No Intervention	No Intervention	No Intervention	No Intervention	No Intervention	No Intervention
<b>Note; No Intervention; No need of intervention within 20 years as the pavement wouldn't reach 4m/km (IRI)</b>						
<b>Non Pavement Routine Maintenance is required every year</b>						



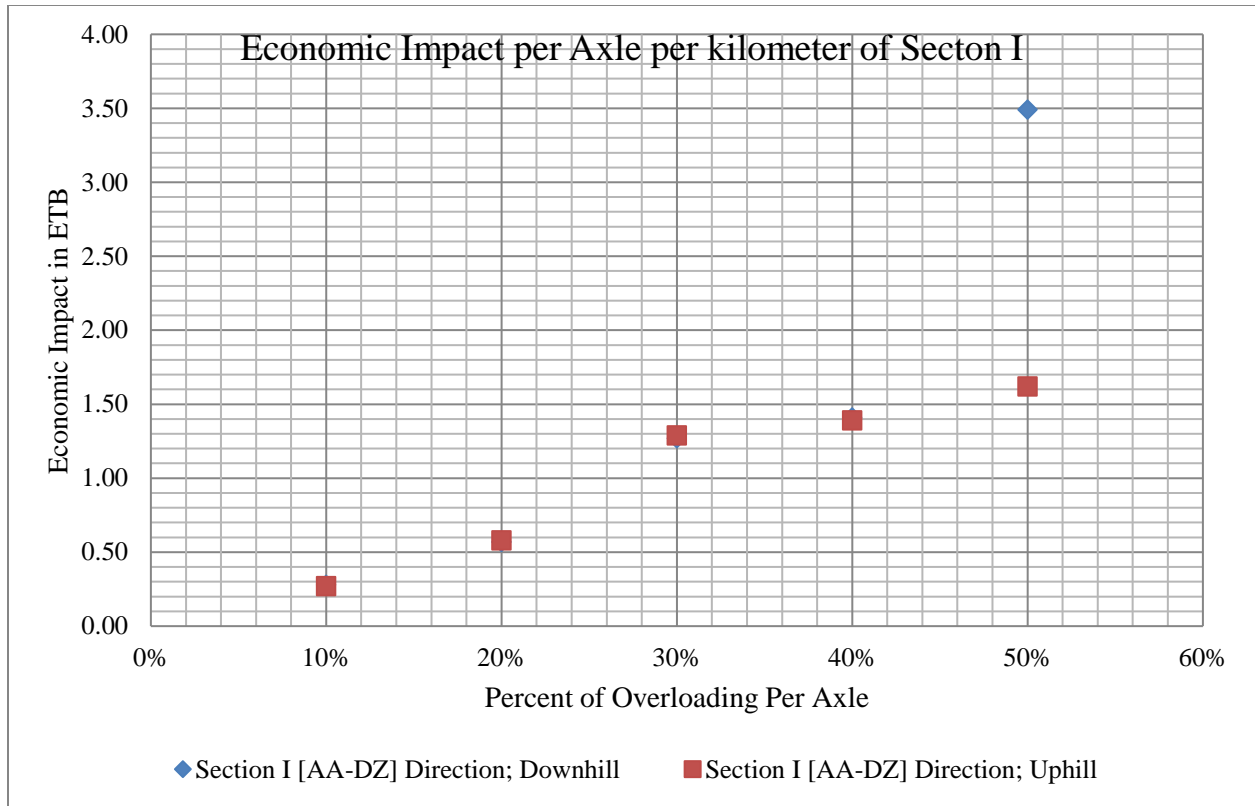
Road Section V [AR-AD]; Direction Up Hill						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
<b>Intervention</b>	No Intervention	No Intervention	No Intervention	No Intervention	No Intervention	No Intervention
<b>Note; No Intervention; No need of intervention within 20 years as the pavement wouldn't reach 4m/km (IRI)</b>						
<b>Non Pavement Routine Maintenance is required every year</b>						

## APPENDIX G I

### Economic Analysis Summary and Distribution of Cost to Overloaded Axles

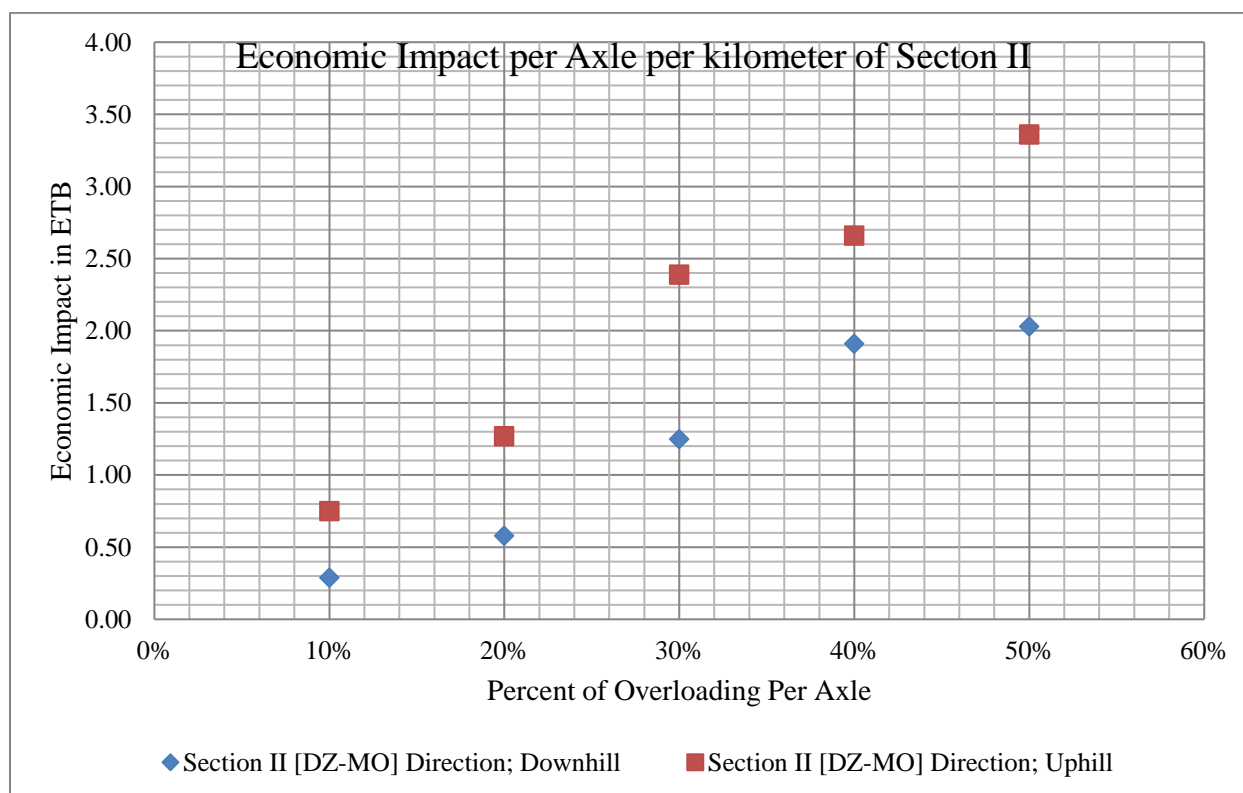
Analysis of Economic Impact per percent of Overloading per kilometer						
		Section I [AA-DZ]	Direction; Uphill	Length (km)	14	
Change in NPV: For Different Overload Cases (millions ETB)						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
NPV	12.56	51.84	73.62	97.54	98.56	99.62
Change in NPV	0	39.28	61.06	84.98	86	87.06
% Overloading	NPV of Revenue from Overloaded Axles (millions)					
0%	0	0.00	0.00	0.00	0.00	0.00
10%	0	10.75	4.39	4.39	4.39	4.39
20%	0	0.00	5.61	3.22	3.22	3.22
30%	0	0.00	0.00	2.39	1.66	1.66
40%	0	0.00	0.00	0.00	0.73	0.40
50%	0	0.00	0.00	0.00	0.00	0.33
Economic Impact per axle per kilometer						
Percent Overload	0%	10%	20%	30%	40%	50%
total	0	3.65	8.02	18.01	19.40	22.60
ETB per km per axle	0	0.27	0.58	1.29	1.39	1.62

		Section I [AA-DZ]	Direction; Downhill	Length (km)	14	
Change in NPV; for different cases (millions ETB)						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
NPV	10.51	49	72.04	95.49	96.93	106.65
Change in NPV	0	38.49	61.53	84.98	86.42	96.14
% Overloading	NPV of Revenue from Overloaded Axles (millions)					
0%	0	0	0	0	0	0
10%	0	9.99	4.41	4.41	4.41	4.41
20%	0	0.00	5.64	3.23	3.23	3.23
30%	0	0.00	0.00	2.40	1.67	1.67
40%	0	0.00	0.00	0.00	0.74	0.40
50%	0	0.00	0.00	0.00	0.00	0.33
Economic Impact per axle per kilometer						
Percent Overload	0%	10%	20%	30%	40%	50%
total	0	3.85	7.90	17.65	19.60	48.81
ETB per km per axle	0	0.28	0.57	1.27	1.41	3.49



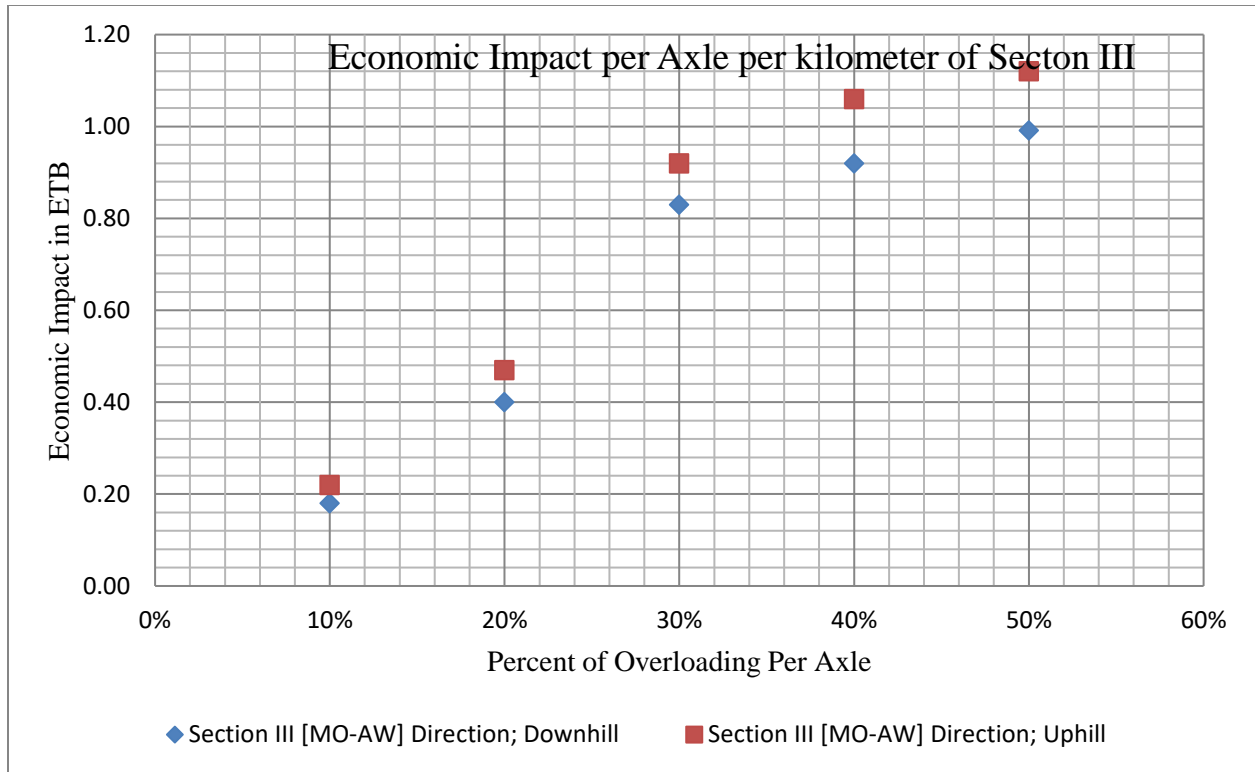
		Section II [DZ-MO]	Direction; Uphill	Length (km)	35	
<b>Change in NPV: For Different Overload Cases (millions)</b>						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
NPV	165.52	570.45	736.38	886.35	897.38	910.28
Change in NPV	165.52	404.93	570.86	720.83	731.86	744.76
% Overloading	<b>NPV of Revenue from Overloaded Axles (millions)</b>					
0%	0.00	0.00	0.00	0.00	0.00	0.00
10%	0.00	15.56	6.52	6.52	6.52	6.52
20%	0.00	0.00	9.04	5.21	5.21	5.21
30%	0.00	0.00	0.00	3.83	2.66	2.66
40%	0.00	0.00	0.00	0.00	1.17	0.65
50%	0.00	0.00	0.00	0.00	0.00	0.52
<b>Economic Impact per axle per kilometer</b>						
Percent Overload	0%	10%	20%	30%	40%	50%
total	0.00	26.03	44.39	83.57	93.01	117.62
ETB per km per axle	0.00	0.75	1.27	2.39	2.66	3.36

Section II [DZ-MO]		Direction; Downhill	Length (km)	35		
Change in NPV: For Different Overload Cases (millions)						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
NPV	45.12	172.17	242.60	314.54	336.20	337.91
Change in NPV	0.00	127.05	197.48	269.42	291.08	292.79
NPV of Revenue from Overloaded Axles (millions)						
% Overloading	0%	10%	20%	30%	40%	50%
0%	0.00	0.00	0.00	0.00	0.00	0.00
10%	0.00	12.43	5.21	5.21	5.21	5.21
20%	0.00	0.00	7.22	4.16	4.16	4.16
30%	0.00	0.00	0.00	3.06	2.12	2.12
40%	0.00	0.00	0.00	0.00	0.93	0.52
50%	0.00	0.00	0.00	0.00	0.00	0.42
Economic Impact per axle per kilometer						
Percent Overload	0%	10%	20%	30%	40%	50%
total	0.00	10.22	19.97	43.49	66.67	70.76
ETB per km per axle	0.00	0.29	0.58	1.25	1.91	2.03



Section III [MO-AW]		Direction; Uphill	Length (km)	8		
<b>Change in NPV: For Different Overload Cases (millions)</b>						
Overload Case	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
NPV	0.83	17.64	29.19	38.12	38.96	39.13
Change in NPV	0.00	16.81	28.36	37.29	38.13	38.30
<b>NPV of Revenue from Overloaded Axles (millions)</b>						
% Overloading	0.00	0.00	0.00	0.00	0.00	0.00
0%	0.00	0.00	0.00	0.00	0.00	0.00
10%	0.00	9.97	4.18	4.18	4.18	4.18
20%	0.00	0.00	5.79	3.34	3.34	3.34
30%	0.00	0.00	0.00	2.45	1.70	1.70
40%	0.00	0.00	0.00	0.00	0.75	0.41
50%	0.00	0.00	0.00	0.00	0.00	0.34
<b>Economic Impact per axle per kilometer</b>						
Percent Overload	0%	10%	20%	30%	40%	50%
total	0.00	1.69	3.68	7.32	8.44	8.95
ETB per km per axle	0.00	0.22	0.47	0.92	1.06	1.12

Section III [MO-AW]		Direction; Downhill	Length (km)	8		
<b>Change in NPV: For Different Overload Cases (millions)</b>						
	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
	0.14	13.97	24.46	32.93	33.51	33.71
	0	13.83	24.32	32.79	33.37	33.57
<b>NPV of Revenue from Overloaded Axles (millions)</b>						
% Overloading	0	0	0	0	0	0
0%	0	0	0	0	0	0
10%	0	10.09	4.23	4.23	4.23	4.23
20%	0	0.00	5.86	3.38	3.38	3.38
30%	0	0.00	0.00	2.48	1.72	1.72
40%	0	0.00	0.00	0.00	0.76	0.42
50%	0	0.00	0.00	0.00	0.00	0.34
<b>Economic Impact per axle per kilometer</b>						
Percent Overload	0%	10%	20%	30%	40%	50%
total	0	1.37	3.16	6.58	7.34	7.93
ETB per km per axle	0	0.18	0.40	0.83	0.92	0.99



## APPENDIX G2

### Cash Flow and Cost Distribution of Weighing Stations Cost to Overloaded Trucks

Year	Initial investment	Annual Management Cost	Total Cost	Average Number of Overloaded Trucks on Road Section I- V		Average Number of Overloaded trucks	NPV Total Cost	NPV of Revenue from Overloaded Trucks
				Downhill	Uphill			
2014	2.00E+07		2.00E+07				2.22E+07	0
2015		717,600	717,600	146,767	131,818	139293	717600	139293
2016		717,600	717,600	156,811	143,183	149997	646486	135133
2017		717,600	717,600	167,657	155,549	161603	582420	131160
2018		717,600	717,600	179,371	169,004	174188	524703	127365
2019		717,600	717,600	192,029	183,648	187839	472705	123735
2020		717,600	717,600	205,711	199,587	202649	425861	120263
2021		717,600	717,600	216,904	210,360	213632	383658	114216
2022		717,600	717,600	228,712	221,726	225219	345638	108479
2023		717,600	717,600	241,171	233,718	237444	311386	103033
2024		717,600	717,600	254,316	246,370	250343	280528	97865
2025		717,600	717,600	268,187	259,720	263954	252728	92960
2026		717,600	717,600	282,822	273,808	278315	227683	88305
2027		717,600	717,600	298,266	288,674	293470	205119	83886
2028		717,600	717,600	314,563	304363	309463	184792	79691
2029		717,600	717,600	331,761	320,920	326341	166479	75709
2030		717,600	717,600	349,910	338,396	344153	149982	71929
2031		717,600	717,600	369,064	356,841	362952	135118	68341
2032		717,600	717,600	389,278	376,310	382794	121728	64934
2033		717,600	717,600	410,612	396,861	403736	109665	61700
2034		717,600	717,600	433,128	418,556	425842	98797	58629
Total NPV							2.85E+07	1.95E+06
						Weighing Station Cost per Vehicle	14.67	

## APPENDIX H

### Statistical comparison between rationalized and court imposed overload fines

S. No	Court imposed fee in (ETB)	Axle Distribution of Vehicles (KN)							Origin	Estimated distance in (Km)	Rationalized Economic Cost (ETB)	Weighing Station Cost	Rationalized overload Charge	Difference	Difference in Money (ETB)
		F1	R1	R2	R3	R4	R5	R6							
1	180	75		119	117				Ziway	87	150.43	14.67	166	8%	14
2	306	57		126	125				Alemtena	40	116.03	14.67	131	134%	175
3	250	64		126	126				Meki	85	224.00	14.67	239	5%	11
4	250	68		127	127				Meki	85	233.63	14.67	249	0%	1
5	516	69		145	141				Debre Zeit	35	119.62	14.67	135	282%	381
6	590	77		130	129	99	70	77	Kibre - mengist	456	1381.12	14.67	1396	-58%	-806
7	300	72		130	130				A.A	55	109.43	14.67	125	140%	175
8	360	70		128	132				Meki	85	261.98	14.67	277	30%	83
9	300	67		133	134				Adama	20	69.26	14.67	84	257%	216
10	300	68		132	131				Adama	20	64.97	14.67	80	275%	220
11	300	66		132	131				Adama	20	64.97	14.67	80	275%	220
12	300	71		132	132				Adama	20	66.06	14.67	81	270%	219
13	390	69		131	134				Wolenchiti	65	218.08	14.67	233	67%	157
14	500	70		134	133				Gintiri	200	468.84	14.67	484	3%	16
15	335	68		132	135				Ziway	87	301.14	14.67	316	6%	19
16	610	70		135	133				A.A	55	131.85	14.67	147	315%	463
17	800	71		135	133				Alemtena	45	158.18	14.67	173	362%	627
18	600	74		132	137	99	75	75	A.A	55	135.02	14.67	150	300%	450
19	500	76		134	135				Ambo	351	859.79	14.67	875	-43%	-375
20	400	77		135	135				Alemtena	40	162.89	14.67	178	125%	222
21	350	68		139	137				Koka	30	117.54	14.67	133	163%	217
22	800	70		135	135				A.A	55	137.65	14.67	153	423%	647
23	420	67		135	135				Debre Zeit	35	126.69	14.67	142	196%	278

24	420	66		135	135				Meki	85	307.68	14.67	323	30%	97
25	426	72		135	136				Alemtena	40	165.19	14.67	180	137%	246
26	366	70		131	130				Alemtena	40	141.27	14.67	156	135%	210
27	426	76		135	136				Ziway	87	319.36	14.67	335	27%	91
28	350	72		135	137				Alemtena	40	167.43	14.67	183	91%	167
29	350	65		135	137				Adama	20	74.41	14.67	90	289%	260
30	500	70		135	133	104	82	87	A.A	55	135.84	14.67	151	231%	349
31	400	77		135	137	99	75	93	A.A	55	143.64	14.67	159	152%	241
32	350	71		137	136				Dire Dawa	406	1531.32	14.67	1546	-77%	-1196
33	350	69		137	136				Dire Dawa	406	1531.32	14.67	1546	-77%	-1196
34	350	71		137	136				Dire Dawa	406	1531.32	14.67	1546	-77%	-1196
35	500	60		136	137				Adama	20	75.43	14.67	91	449%	409
36	150	69		137	136				Koka	30	113.15	14.67	128	17%	22
37	300	70		138	136				Alemtena	40	171.92	14.67	187	60%	113
38	700	75		130	140	104	74	86	A.A	55	142.85	14.67	158	343%	542
39	500	68		136	138				Debre Zeit	35	95.25	14.67	110	355%	390
40	400	71		137	137				A.A	55	149.63	14.67	165	142%	235
41	444	65		136	138				Debre Zeit	35	95.25	14.67	110	304%	334
42	350	76		137	138				Meki	85	328.99	14.67	344	2%	6
43	358	76		140	135				Dire Dawa	406	1568.53	14.67	1584	-77%	-1226
44	350	72		137	138				Adama	20	77.41	14.67	93	276%	257
45	300	67		136	137				Adama	20	75.43	14.67	91	230%	209
46	750	79		132	134	109	89	97	A.A	55	136.61	14.67	152	393%	598
47	500	50		137	139				A.A	55	155.80	14.67	171	192%	329
48	700	60		139	137				Dire Dawa	406	1590.72	14.67	1606	-56%	-906
49	350	76		138	138				Alemtena	40	176.37	14.67	192	82%	158
50	700	71		137	139				Debre Zeit	35	99.15	14.67	114	514%	586
51	700	62		137	139				Debre Zeit	35	99.15	14.67	114	514%	586
52	456	62		138	138				Adama	20	78.39	14.67	94	385%	362

53	456	82		138	138				Adama	20	80.18	14.67	95	380%	361
54	350	71		139	138				Adametulu	130	515.69	14.67	531	-34%	-181
55	200	78		138	139				Adamitulu	130	515.69	14.67	531	-62%	-331
56	350	70		138	139				Alemtena	45	178.51	14.67	194	80%	156
57	350	73		139	138				Alemtena	45	178.51	14.67	194	80%	156
58	350	73		139	138				Wolenchiti	65	257.84	14.67	273	28%	77
59	300	75		138	139				Langano	150	1190.05	14.67	1205	-75%	-905
60	800	67		134	141	100	91	102	A.A	55	155.11	14.67	170	371%	630
61	400	69		138	139				Diredawa	410	1626.40	14.67	1642	-76%	-1242
62	400	70		140	138				Adama	20	80.26	14.67	95	321%	305
63	340	76		140	138				Langano	150	601.97	14.67	617	-45%	-277
64	350	83		140	138				Sodere	60	249.11	14.67	264	33%	86
65	500	72		138	140				Adama	20	80.26	14.67	95	426%	405
66	800	73		138	140				A.A	55	162.03	14.67	177	352%	623
67	400	76		140	138				Hawassa	205	822.69	14.67	838	-52%	-438
68	390	70		139	139				Alemtena	45	180.65	14.67	196	99%	194
69	350	80		140	139				Ziway	87	353.28	14.67	368	-5%	-18
70	500	75		140	139				Alemtena	45	182.73	14.67	198	153%	302
71	500	67		145	138	108	68	83	Afdera	680	3091.38	14.67	3107	-84%	-2607
72	400	68		140	139				Adama	20	81.21	14.67	96	317%	304
73	350	71		139	140				Alemtena	45	182.73	14.67	198	77%	152
74	480	78		137	142				Alemtena	45	182.37	14.67	198	142%	282
75	553	71		139	140				Langano	150	609.10	14.67	624	-11%	-71
76	395	71		140	139				Alemtena	40	182.73	14.67	198	99%	197
77	600	64		140	140				A.A	55	168.30	14.67	183	228%	417
78	400	84		140	140				Dukem	50	157.69	14.67	173	131%	227
79	400	70		140	140				Langano	150	616.04	14.67	631	-37%	-231
80	500	79		138	142				Ziway	87	356.82	14.67	372	34%	128
81	400	70		140	140				Sodere	60	246.42	14.67	262	53%	138

82	300	65		140	140				Alemtena	45	184.81	14.67	200	50%	100
83	400	71		138	142				Alemtena	45	184.56	14.67	200	100%	200
84	400	70		140	140				Ziway	87	357.31	14.67	372	8%	28
85	400	72		140	140				Adama	20	82.14	14.67	97	312%	303
86	400	67		139	136	105	86	93	A.A	55	157.94	14.67	173	131%	227
87	400	70		140	140				Alemtena	45	184.81	14.67	200	100%	200
88	500	78		140	140				Langano	150	616.04	14.67	631	-21%	-131
89	800	78		137	142				Alemtena	45	182.37	14.67	198	304%	602
90	400	68		140	140				Welenchiti	65	266.95	14.67	282	42%	118
91	500	70		140	140				Adama	20	82.14	14.67	97	415%	403
92	400	73		140	140				Welenchiti	65	266.95	14.67	282	42%	118
93	500	79		134	143	102	101	100	A.A	55	162.55	14.67	178	181%	322
94	500	56		136	135	104	88	105	A.A	55	149.77	14.67	165	203%	335
95	400	73		140	140				Langano	150	616.04	14.67	631	-37%	-231
96	480	72		140	140				Meki	85	349.09	14.67	364	32%	116
97	480	71		140	140				Ziway	87	357.31	14.67	372	29%	108
98	546	74		147	147				Debre Zeit	35	136.82	14.67	152	259%	394
99	480	71		140	140				Ziway	87	357.31	14.67	372	29%	108
100	800	65		98	102	138	140		A.A	55	163.88	14.67	179	347%	621
101	200	68		140	140				Langano	150	616.04	14.67	631	-68%	-431
102	567	76		135	139	110	90	91	A.A	55	161.82	14.67	177	220%	390
103	400	68		140	141				Adama	20	83.04	14.67	98	308%	302
104	400	78		141	140				Sodere	60	249.11	14.67	264	52%	136
105	500	69		140	141				Bulbula	120	498.22	14.67	513	-3%	-13
106	800	49		139	142				A.A	55	171.59	14.67	187	328%	613
107	810	84		110	115	114	138		A.A	55	134.16	14.67	149	444%	661
108	800	67	65	124	126	125	94	106	Djibouti	676	2700.54	14.67	2716	-71%	-1916
109	405	69		149	145				Meki	85	396.06	14.67	411	-1%	-6
110	500	71		141	141				Sodere	60	251.80	14.67	267	87%	233

111	500	72		142	140				Sodere	60	251.71	14.67	267	87%	233
112	400	70		139	143				Ziway	87	364.60	14.67	380	5%	20
113	500	71		141	141				Wolenchiti	65	272.79	14.67	288	74%	212
114	600	98		127	121	116	63	84	Djibouti	676	2864.69	14.67	2880	-79%	-2280
115	800	83		110	113	135	121		Djibouti	676	2686.71	14.67	2702	-70%	-1902
116	492	71		141	141				Ziway	87	365.12	14.67	380	29%	112
117	498	72		141	142				Bulbula	120	508.82	14.67	524	-5%	-26
118	500	61		130	160				Meki	85	349.89	14.67	365	37%	135
119	400	71		143	143				Langano	150	655.09	14.67	670	-40%	-270
120	500	74		142	142				Bulbula	120	514.02	14.67	529	-5%	-29
121	420	70		142	142				Alemtena	45	192.76	14.67	208	102%	212
122	840	38		137	147	95	71	74	Djibouti	676	2869.31	14.67	2884	-71%	-2044
123	600	77		140	140	105	100	98	Afdera	676	2905.02	14.67	2920	-79%	-2320
124	600	79		140	145				Adama	20	86.32	14.67	101	494%	499
125	400	78		142	143				Adama	20	86.51	14.67	102	292%	298
126	500	64		140	145				Ziway	87	375.47	14.67	391	28%	109
127	500	72		143	143				Adama	20	87.34	14.67	103	385%	397
128	400	69		141	145				Bulbula	120	523.28	14.67	538	-26%	-138
129	522	75		139	142	106	80	95	A.A	55	177.99	14.67	193	170%	329
130	900	72		145	143				Shekiso	400	1778.36	14.67	1794	-50%	-894
131	400	76		135	135	120	74	84	Afdera	676	3092.89	14.67	3108	-87%	-2708
132	800	68		121	118	127	122		A.A	55	140.63	14.67	156	413%	644
133	500	75		145	144				Adama	20	89.72	14.67	105	376%	395
134	450	79		145	145				Alemtena	45	203.61	14.67	219	105%	231
135	450	71		145	145				Meki	85	384.59	14.67	400	13%	50
136	600	62		145	145	100			Djiboti	676	3058.62	14.67	3074	-80%	-2474
137	500	76		140	150	100	99	75	A.A	55	246.36	14.67	262	91%	238
138	400	68		145	145				Alemtena	45	164.64	14.67	180	122%	220
139	900	64		145	145				Debre Zeit	35	158.36	14.67	174	417%	726

140	900	67		140	140				Djibouti	676	2776.30	14.67	2791	-68%	-1891	
141	540	78		145	145				Debre Zeit	35	128.05	14.67	143	278%	397	
142	600	74		145	145				Alemtena	45	203.61	14.67	219	174%	381	
143	450	73		146	145				Meki	85	387.71	14.67	403	12%	47	
144	546	70		144	147				A.A	55	204.73	14.67	220	148%	326	
145	400	63		145	147				Debre Zeit	35	132.43	14.67	148	170%	252	
146	600	52		131	132	129	59	62	Debrezeit	35	107.98	14.67	123	388%	477	
147	450	70		147	145				Langano	150	689.40	14.67	705	-36%	-255	
148	400	72		150	145				Alemtena	45	210.96	14.67	226	77%	174	
149	700	63		125	121	110	140		Mekele	973	4618.40	14.67	4634	-85%	-3934	
150	600	68		149	147				Sodere	60	283.85	14.67	299	101%	301	
151	785	75		148	149				Langano	150	714.55	14.67	730	8%	55	
152	1000	70		150	150				A.A	55	236.27	14.67	251	298%	749	
153	500	80		150	150				Alemtena	45	218.32	14.67	233	115%	267	
154	606	70		150	151				Debre Zeit	35	152.66	14.67	168	261%	438	
155	1000	46		128	123	124	127		Djibouti	676	3456.82	14.67	3472	-71%	-2472	
156	1000	71		143	146	117	95	84	A.A	55	222.21	14.67	237	322%	763	
157	600	54		139	139	138	74	84	A.A	55	239.86	14.67	255	135%	345	
158	600	79		127	131	107	81	103	Afdera	676	2270.38	14.67	2286	-74%	-1686	
Total																
77634													84874			

A.A = Addis Ababa

## STATEMENT OF THE AUTHOR

The author declares that this thesis work is his original work and that all sources of materials used for this thesis have been dully acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. Degree at the Addis Ababa University and is deposited at the University Library to be made available to borrowers under rules of the Library. The author declares that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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