

**ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL
ENGINEERING**



**MANAGEMENT OF LOAD BALANCE AND ITS IMPACT ON
PAVEMENT CONDITIONS
A CASE STUDY ON ADAMA – MILLE ROUTE**

A Thesis in Road and Transport Engineering

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Submitted in Partial Fulfillment of the Requirements for the Degree
of Master of Science

**ADDIS ABABA UNIVERSITY
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ENGINEERING**

As members of the examining board of the final M.Sc. Open Defense, we verify that we have read and evaluated the thesis prepared by **Hiwot Mesele**, entitled: **Management of Load Balance and Its Impact on Pavement Conditions: A Case Study on Adama – Mille Route** and recommended for acceptance as a fulfillment of the requirement for the degree of **Master of Science in Civil Engineering (Road and Transport Engineering)**.

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I, the undersigned, declare that this thesis is my original work and it has not been presented for a degree in any other university. All sources of material used for the thesis have been duly acknowledged.

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ABSTRACT

Road infrastructure is one of the transport infrastructures that play an important role in improving the accessibility of areas and the residents' mobility. However, the availability of different loading condition between the two directions of the road causes deterioration of more heavily trafficked lane of the pavement before reaching the design life. This is due to the absence of different treatment for heavily trafficked lane during pavement design, construction or service stage. The objective of this research was to study the management of load balance in the two directions of the road and its impact on pavement conditions; and to develop solutions to minimize the constraints causing pavement damages. The research was conducted using both primary and secondary data. Primary data has been collected through measurement, observation and questionnaire; and secondary data has been collected from relevant private and governmental offices. The questionnaire is prepared for four target groups namely; pavement Engineers, drivers, vehicle weight and size control team; and control station staff. To analyze the data AASHTO Fourth Power Law, Surface Damage Index (Is), Little's Law and Descriptive Statistics has been used. From the study, it was found that, the actual pavement service life of heavily trafficked lane was reduced by 71% and the actual pavement service life of less trafficked lane was increased by 55% when compared with the pavement design life. The existing load also caused 79.4% load associated failures on heavily trafficked lane and only 4% load associated failures on less trafficked lane which includes the effect of overtaking. Furthermore, due to unavailability of vehicle weight and size control station at the loading place, vehicles are weighed after damaged 401 Km length of road pavement and the penalty taken on the overloaded vehicles is not as per the regulation. Finally, recommendations have been made to use combined pavement or design the lanes separately and to establish effective, strict, uniform and adequate vehicle weight and size control stations at the loading place.

Keywords: Freight Transport, Road Infrastructure, Load Balance, Load Associated Failure, Pavement Deterioration, Pavement Service Life, Pavement Surface Condition, Management

Table of Contents

ACKNOWLEDGMENT	iv
ABSTRACT	v
ABBREVIATIONS	x
1. INTRODUCTION	1
1.1 General	1
1.2 Statement of Problems.....	2
1.3 Research Questions	3
1.4 Objective	3
1.5 Significance of the Study	3
1.6 Hypothesis	3
2. LITERATURE REVIEW	4
2.1 Road network in Ethiopia.....	4
2.2 Road pavement.....	4
2.2.1 Flexible (Bituminous) pavement	5
2.2.2 Rigid (Concrete) pavement.....	5
2.3 Types of flexible pavement failures and its Causes	5
2.4 Strength of road pavement	14
2.5 Road pavement surface condition	15
2.6 Different traffic loading condition experience in different countries.....	17
2.7 Axle load survey for pavement design	19
2.8 Axle configuration.....	19
2.9 Traffic volume and vehicle classification.....	19
2.10 Damaging effect of overloading on pavement	20
2.11 Overloading control system.....	21
3. MATERIAL AND METHODS	26
3.1 Road segment selection	26
3.2 Data collection.....	27
3.2.1 Field observation and measurement	27
3.2.2 Questionnaire.....	30
3.2.3 Secondary data.....	30
3.3 Data analysis.....	30
4. RESULTS	33
5. DISCUSSIONS	54
6. CONCLUSIONS	66
7. RECOMMENDATIONS	68

[ANNEX](#)

List of Tables

Table 1. Deflection bowl parameter structural condition rating criteria^[16] 14

Table 2. Level of Severity of Type A damage^[18] 15

Table 3. Level of Severity of Type B damage^[18] 15

Table 4. External Trade of Ethiopia (National Bank of Ethiopia Annual Report, 2013/2014) 17

Table 5. Material Flow between Ethiopia and Djibouti (Ethiopian Revenues and Customs Authority's good flows data) 18

Table 6. Vehicle Classification (ERA Pavement Design Manual Volume 1: Flexible Pavement, 2002) 20

Table 7. Overloading History at Awash Vehicle Weight and Size Control Station 20

Table 8. Overloading History at Modjo Vehicle Weight and Size Control Station 21

Table 9. Maximum Permissible Axle Load Limits^{[23],[24]} 22

Table 10. Comparison of the Maximum Level of Fees/Fines^[23] 24

Table 11. Type and Source of Secondary Data 30

Table 12. Structural Condition of Adama - Awash Road Segment, Import Lane 38

Table 13. Structural Condition of Adama - Awash Road Segment, Export Lane 38

Table 14. Structural Condition of Awash – Awash Arba Road Segment, Export Lane 39

Table 15. Structural Condition of Awash – Awash Arba Road Segment, Import Lane 39

Table 16. Summary of Cause of Existing Failures per Lane and Different Case 42

Table 17. Weighed Number of Vehicles at Awash Vehicle Weight and Size Control Stations. 44

Table 18. Weighed Number of Vehicles at Modjo Vehicle Weight and Size Control Stations. 46

Table 19. Queue Analysis Result at Awash vehicle weight and size control station...... 47

Table 20. Queue Analysis Result at Modjo vehicle weight and size control station...... 48

List of Figures

Figure 1. Federal Road Network Growth ^[2]	4
Figure 2. Load Distribution of Flexible Pavement ^[5]	5
Figure 3. Load Distribution of Rigid Pavement ^[5]	5
Figure 4. Alligator Cracking ^[8]	7
Figure 5. Longitudinal Cracking ^[8]	7
Figure 6. Transverse Cracking ^[8]	8
Figure 7. Block Cracking ^[8]	8
Figure 8. Reflective Cracking (www.pavementinteractive.org)	8
Figure 9. Edge Cracking ^[9]	9
Figure 10. Rutting without Shoving ^[8]	10
Figure 11. Rutting with Shoving (NET Consult Consulting Engineers and Architects Plc)....	10
Figure 12. Corrugation (www.fhwa.dot.gov).....	11
Figure 13. Corrugation (www.fhwa.dot.gov).....	11
Figure 14. Depression (www.pavementinteractive.org)	11
Figure 15. Swelling (www.pavemanpro.com)	12
Figure 16. Potholes ^[10]	12
Figure 17. Patching (NET Consult Consulting Engineers and Architects Plc).....	13
Figure 18. Raveling ^[5]	13
Figure 19. Bleeding ^[14]	13
Figure 20. Polishing ^[11]	14
Figure 21. Flow Chart of determination of damage index ^[18]	16
Figure 22. Axle Configuration ^[20]	19
Figure 23. Components of a basic queuing system ^[27]	25
Figure 24. Selected Road Segment (Map Data@2016 Google, ORION-ME).....	26
Figure 25. Sample Pictures (A represent Djibouti-Addis Ababa lane and B is vice versa)	27
Figure 26. Vehicles under Examination at Awash and Modjo Control Stations	27
Figure 27. Rut Depth Measurement during Pavement Condition Survey.....	28
Figure 28. Deflection Data Collection.....	29
Figure 29. Vehicles on Queue at Awash and Modjo Control Stations	29
Figure 30. Mean Equivalent Standard Axles (ESAs) per Lane and Road Segment.....	33
Figure 31. Design Vs Actual Service Life of Pavement per Lane and Road Segment	34
Figure 32. Surface Damage Index per lane (0.0-33.5 km)	35
Figure 33. Surface Damage Index per lane (33.5-89.0 km)	35
Figure 34. Surface Damage Index per lane (89.0 – 124.5 km).....	36
Figure 35. Surface Damage Index per lane (124.5 – 202.0 km).....	36
Figure 36. Surface Damage Index per lane (202.0-292.5 km)	37
Figure 37. Pavement Surface Condition per Lane.....	38
Figure 38. Deflection difference between import and export lanes	40
Figure 39. Identified Pavement Failure Location per Lane	40
Figure 40. Cause of Identified Failures per Lane, Case I	40
Figure 41. Cause of Identified Failures per Lane, Case II	41
Figure 42. Cause of Identified Failures per Lane, Case III.....	41
Figure 43. Cause of Identified Failures per Lane, Case IV	41
Figure 44. Summary of Cause of Existing Failures per Lane.....	42
Figure 45. Selection of EF to analyze ESA per design period of the road	43
Figure 46. Summary of Load Associated Failure Per Road Segment	44

Figure 47. Penalized Number of Vehicles (Awash) 45
Figure 48. Penalized Number of Vehicles (Awash) 45
Figure 49. Variance of Overload Charge from Mean (Awash) 46
Figure 50. Penalized Number of Vehicles (Modjo)..... 46
Figure 51. Corrections on Excess Load (Modjo)..... 47
Figure 52. Variance of Overload Charge from Mean (Modjo) 47
Figure 53. Queue Variation per time at Awash vehicle weight and size control station..... 48
Figure 54. Queue Variation per time at Modjo vehicle weight and size control station 48
Figure 55. Permission to travel further without correct the excess load..... 50
Figure 56. Legal axle load limit..... 51
Figure 57. Measures taken on overloaded vehicles 52
Figure 58. Transparency of measures on overloaded vehicles..... 53

ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
BB	Benkelman Beam Deflection
COMESA	Common Market for Eastern and Southern Africa
EAC	East African Community
EF	Equivalent Factor
ERA	Ethiopian Roads Authority
ESAs	Equivalent Standard Axles
ETB	Ethiopian Birr
FCFS	First-Come-First Served
FIFO	First In First Out
FWD	Falling Weight Deflectometer
GDP	Growth Domestic Product
GTP	Growth and Transformation Plan
Is	Surface Damage Index
JICA	Japan International Cooperation Agency
PCC	Portland Cement Concrete
RSDP	Road Sector Development program
SADC	Southern African Development Community
SIRO	Served In Random Order
USD	United State Dollar

1. INTRODUCTION

1.1 General

Road infrastructure is one of the transport infrastructures that play an important role in social and economic growth. Recognizing the importance of road transport in supporting social and economic growth and its role as a catalyst to meet poverty reduction, the Government of Ethiopia has formulated the Road Sector Development program (RSDP). As a result of RSDPs the federal road network length has grown from 15,870 Km in 1997 to 27,606 km in 2015 out of which about 49% is paved while the rest is unpaved. However, the expansion of road infrastructure is not the indicator of good condition of roads. Even if, the federal road network length has grown, most of roads in Ethiopia are observed with failures. Out of the total federal road network, 51% is under good condition, 27% fair and 22% poor condition, which shows that almost half of the road network requires maintenance. There are two major factors which cause structural damage to the road pavement, internal factor which is related to construction problem and external factor which is related to temperature, road surface water drainage system and traffic load.

However, the axle load and its repetition are the major factors which cause damage on road pavement. As Crockford (1993) put it: the application of tire contact pressure or axle load above the carrying capacity of the pavement is the fundamental cause of pavement failure. The tire contact pressure can be reduced by increasing the number of axles, the number of tires and by reducing the inflation pressure of tires. That is why the gross vehicle weight is unlimited by the pavement structures ^[1].

The passage of each vehicle has a cumulative effect for road deterioration. However, research has shown that light vehicles such as cars and light commercial vehicles make a relatively small contribution to the structural damage of a road pavement compared to that of heavy vehicles and the load carried by each axle determines its destructive effect. The damage caused by heavy vehicle is determined by the magnitude of axle loads, spacing between the axles, the number of wheels, the contract pressures of the tyres and the traveling speed ^[21]. According to Addis M. 2015, 48% of overloading reduces the service life of pavement from 20 years design life to 11 years and it requires 12.2cm overlay thickness to carry additional load caused by overloading.

To protect the road infrastructure assets from failure caused by overloading, Ethiopian Roads Authority (ERA) has established ten static weighbridge stations and two mobile weighbridges

with a regulation of axle load limits 8 tonnes for front axle and 10 tonnes for rear axle. Due to this, during the design period, Equivalent Standard Axle Load (ESALs) were computed excluding axle loads in excess of legal axle load limit by considering that the traffic carried by the road in future will be within the legal axle load limits of the traffic. Hence, the ESAL caused by overloaded truck traffic is not the expected traffic load in pavement design. As a result, the bearing capacity of pavement is lower than the actual demand which causes different types of pavement failures and it induced unexpected expenditure on pavement investment.

1.2 Statement of Problems

According to Ethiopian Revenues and Customs Authority's goods flow data between Addis Ababa and Djibouti from 2010 to 2014, which is the main import-export corridor in Ethiopia, the average exported material is only 12% of the average imported material and most of the vehicles along the export lane is empty running. Which means the heavy traffic loading condition along Addis Ababa to Djibouti route is not balance. Due to this different traffic loading condition between the two lanes, the load is higher on the import (left) lane. However, without implementation of axle load control stations to control the excess load above the legal limit, any kind of consideration is not applied during design, construction and service stage of road to handle the load difference.

During the design period, the actual load on the heavily trafficked lane is not considered by bearing in mind that the traffic carried by the road in future will be within the legal axle load limit of the traffic and both lanes are designed with the same standard using legal axle load limit. The consideration of legal axle load limit for design purpose is not optimal solution. It can save the less trafficked lane from failure but it is not economical because the traffic load along the less trafficked lane is very small and around 84% of vehicles running along this lane are empty. Furthermore, this consideration reduces the expected bearing capacity of heavily trafficked lane to carry the actual load. Subsequently, pavement failures especially rutting is occurred on heavily trafficked lane and it induced unexpected expenditure on pavement investment.

Ethiopian Roads Authority (ERA) has established axle load control stations to control the excess load and protect the road infrastructure assets from failure caused by overloading. However, the location of the first vehicle weight and size control station along Addis Ababa to Djibouti route is 401 Km far from the port. In addition, the road after the control station also under distress which is the main indicator of ineffectiveness of existing vehicle weight

and size control stations. Furthermore, the handling system of queuing at the control station has its own effect on the damage of pavement near to the station. There is no separated queuing area in the control station. Hence, vehicles are stopped on the main road when there is queue and it can affect the pavement condition through time.

1.3 Research Questions

This thesis mainly focused to address the following research questions;

- How much is the pavement service life reduced by the currently occurring imbalance in goods flows?
- How much is the load associated failures occurred by the currently occurring imbalance in goods flows?
- Does the pavement condition depend on the management of imbalance in goods flows?
- How the queue system functions at the control stations?

1.4 Objective

The main objective of this thesis was to study the management of load balance and its impact on pavement conditions along Adama - Mille route in Ethiopia to develop solutions and minimize the constraints causing pavement damages.

The specific objectives of this thesis were to:

- estimate the reduced pavement service life due to the existing imbalance in goods flows
- estimate the impact of existing imbalance in goods flows on pavement conditions
- study the management of imbalance in goods flows
- identify the service mechanism and handling of the queue system at the control station

1.5 Significance of the Study

The thesis will develop solutions to minimize the constraints causing pavement damages and unexpected expenditure on pavement investment.

1.6 Hypothesis

- Management of load balance affect the pavement condition and pavement service life.

2. LITERATURE REVIEW

2.1 Road network in Ethiopia

Road infrastructure is one of the transport infrastructures that play an important role in improving the accessibility of area and population mobility. It should build to provide a safe and comfort riding service for the public throughout the design period without major maintenance.

Road infrastructure in Ethiopia provides a dominant service for freight and passenger transport and it plays an important role in the economy of the country. The Government of Ethiopia has formulated the Road Sector Development program (RSDP) to address constraints in the road sector, mainly low road coverage and poor condition of the road network^[2,3].

As a result of RSDP the federal road network has expanded from 15,870 km in 1997 to 27,606 km in 2015 out of which about 49% is paved while 51% is unpaved^[2].

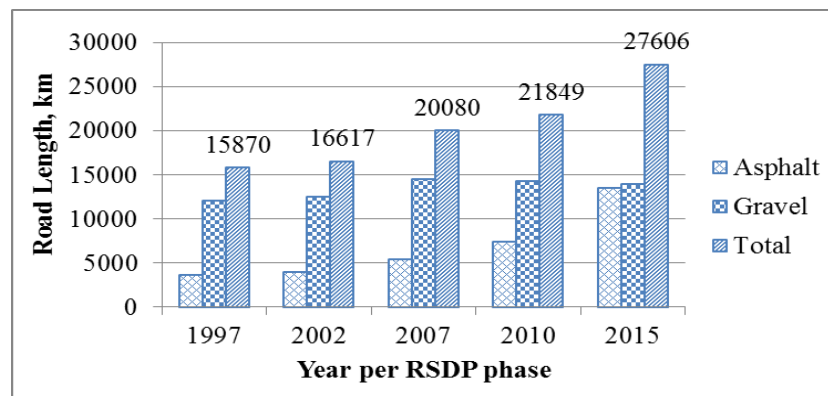


Figure 1. Federal Road Network Growth^[2]

However, out of the total federal road network 51% is under good condition, 27% fair and 22% poor which shows that almost half of the road network requires maintenance^[2].

2.2 Road pavement

“A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the subgrade. Improper design of pavements leads to early failure of pavements

affecting the riding quality.” [4] There are two major types of pavements, flexible pavements and rigid pavements.

2.2.1 Flexible (Bituminous) pavement

Flexible pavements are constructed of superimposed layers of natural granular material with different layer strength. The strength difference between the pavements layers are used to change the load distribution pattern from layer to layer. If the applied load on the pavement is higher, the flexible pavement will flex (bend) and it causes pavement failure [5].

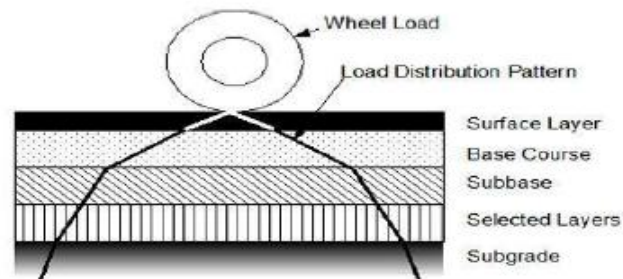


Figure 2. Load Distribution of Flexible Pavement [5]

2.2.2 Rigid (Concrete) pavement

Rigid pavements are made with a Portland Cement Concrete (PCC) surface course and it is stiffer than flexible pavements due to high modulus elasticity of the PCC material [5]. The wheel load applied on the rigid pavement is transferred to sub grade by flexural strength and the rigid pavement is acts like a rigid plate [4].

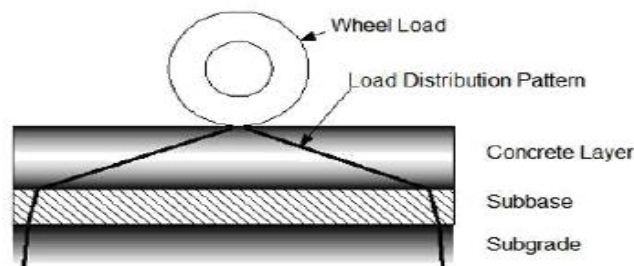


Figure 3. Load Distribution of Rigid Pavement [5]

2.3 Types of flexible pavement failures and its Causes

Pavement failure is a condition of pavement structure that reduces serviceability or leads to a reduction in serviceability. There are two major factors which cause structural damage to the road pavement; internal cause which is related to the implementation of pavement quality during construction, and external cause which is related to temperature, road surface water drainage system and traffic load. However, the fundamental cause of

pavement failure is the application of a tire contact pressure that exceeds the load carrying capacity of the pavement ^[6].

The major categories of asphalt pavement distress are cracking, surface deformation, disintegration (potholes, etc.) and surface defects (bleeding, etc.) ^[5]. Common types of failures and its causes are discussed as shown below.

A. Cracking

According to ERA Pavement Rehabilitation and Asphalt Overlay Design Manual, 2013, Cracking is divided in to wheel path cracking and non-wheel path cracking to identify the cause of the deterioration.

Wheel path cracking

The crack which occurred on the wheel path is the primary indicator of failure due to loading (traffic associated cracking). If cracking is caused primarily by traffic, it must originate in or near the wheel paths.

Non Wheel path cracking

The occurrence of cracking out of the wheel path area and the absence of substantial rutting is the major indicator of non-traffic associated cracking. Non wheel path cracking includes longitudinal, transverse, block and crocodile cracking. The most common types of cracking could be described below.

Fatigue cracking (Alligator cracking)

Alligator crack is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue) ^[5]. A pattern crack which occurs at area which is not subjected to loading is considered as block crack which is not load associated crack ^[10]. Increase in loading (more or heavier loads than anticipated in design), decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade), inadequate structural design and poor construction (inadequate compaction) is the main cause of fatigue crack ^[7].

According to ERA Pavement Rehabilitation and Asphalt Overlay Design Manual, 2013, short irregular longitudinal cracks in the wheel paths are the first stage of traffic induced fatigue of the surface and by further trafficking these cracks will interconnect to form alligator crack. Even if, alligator cracks initiate at the bottom of asphalt surfacing, in tropical climates cracks can initiate at the top of the surfacing because the

bitumen at the top of asphalt wearing course oxidizes rapidly and the material become brittle. Alligator crack which occur out of the wheel path area or not associated with the rutting is caused by construction problem.



Figure 4. Alligator Cracking^[8]

Longitudinal cracking

Longitudinal crack is a type of crack that runs parallel to the center line of the roadway which is caused by frost heaving or joint failures or they may be load induced^[5]. This type of cracking also caused by differential consolidation between old and new fills, and wetting up of newly constructed fill slopes^[9].

According to ERA Pavement Rehabilitation and Asphalt Overlay Design Manual, 2013, short irregular longitudinal cracks in the wheel paths are the first stage of traffic induced fatigue of the surface and by further trafficking these cracks will interconnect to form alligator crack. Long longitudinal cracks are the result of subgrade movement.

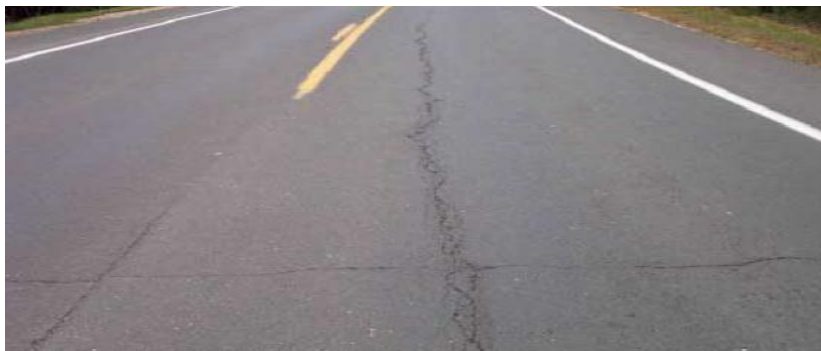


Figure 5. Longitudinal Cracking^[8]

Transverse cracking

Transverse crack is a type of crack which runs approximately perpendicular to the centerline of the road. Transverse cracking has the same cause with longitudinal cracking. Moreover, low temperature cracking can exist due to thermal issue if the asphalt cement is too hard^[5]. Poor compaction at drainage structures can also cause transverse crack^[9].



Figure 6. Transverse Cracking ^[8]

Block (Multiple) cracking

Block crack is an interconnected series of cracks which divide the pavement in to irregular pieces. Block crack is the intersecting of transverse and longitudinal cracks and lack of compaction during construction is the cause of this type of crack ^[5]. Shrinkage of treated (stabilized) pavement layers due to thermal stress also the main cause of block cracking ^[9]. Even if, the severity of crack increases from low to medium to high due to traffic loading, it is not a load associated failure ^[10].



Figure 7. Block Cracking ^[8]

Reflective cracking

Reflective crack is any type of crack which reflects up through the overlaid (repaired) surface with hot mix asphalt concrete ^[5].



Figure 8. Reflective Cracking (www.pavementinteractive.org)

Edge cracking

Edge crack is a type of crack which starts at the edge of the pavement with crescent shape and expand until it begins to resemble alligator cracking ^[5]. Inadequate pavement width, inadequate edge support, traffic traveling on shoulder edge and weak seal coat or loss of adhesion is the possible causes of edge cracking ^[11].



Figure 9. Edge Cracking ^[9]

B. Surface deformation:

Pavement deformation is a major category of asphalt pavement distress which causes from pavement weakness in one or more layers of the pavement ^[5]. The basic types of surface deformation could be described as below.

Rutting

Rutting is a surface deformation in one or more layers of pavement by displacement of pavement material which creates channels in the wheel path under traffic ^[5]. Inadequate compaction, inadequate pavement thickness and instability of base may cause rutting ^[11].

According to ERA Pavement Rehabilitation and Asphalt Overlay Design Manual, 2013, rutting is divided in to rutting without shoving and rutting with shoving to identify the cause of the deterioration.

Rutting without shoving

Rutting without shoving is wide and occurs without shoving at the edge of the ruts because it is primarily caused by the movement deep in the pavement structure. The main possible causes of this type of ruts are excessive traffic loading, insufficient load spreading (inadequate pavement thickness) or secondary compaction. If there is significant difference in traffic loading between the two lanes, initial deterioration is the result of excessive traffic loading and /or inadequate pavement layer thickness for subgrade strength. Otherwise, the cause of rutting will be secondary compaction of

one or more of the pavement layers by traffic and the increasing of rut will decrease after the initial compaction phase ^[12].



Figure 10. Rutting without Shoving ^[8]

Rutting with shoving

In this case shoving is occurred at the edge of the ruts and it is the indicative of shear failure in one of the pavement layers. The main cause of this type of rut is inadequate shear strength of the pavement to resist the applied traffic stress at that particular depth of the pavement due to poor quality surfacing material and inappropriate surfacing material for temperature and/or loading regime. The failures are usually to the upper pavement layers which have high traffic stress and unlike the rutting without shoving, it is not related to the overall strength of the pavement ^[12].



Figure 11. Rutting with Shoving (NET Consult Consulting Engineers and Architects Plc)

Corrugation

Corrugation is a shallow and evenly spaced ridges of the pavement surface material which existing transverse to road axis. It results from a lack of cohesion in the surface material and displacement by moving vehicles ^[13]. Too much asphalt cement, too much fine aggregate or rounded or smooth textured course aggregate may cause the lack of cohesion or instability of the asphalt concrete surface. Corrugation mostly occurred at the places where vehicles accelerate or decelerate ^[5].



Figure 12. Corrugation (www.fhwa.dot.gov)

Shoving

Shoving is a longitudinal and associated vertical displacement of a localized area of the pavement surface. This type of deformation mostly occurred on hills, curves and at intersections due to braking and accelerating of vehicles ^[14]. Poor bond between layers, Lack of edge containment and inadequate pavement thickness may also be the possible causes of shoving ^[11].



Figure 13. Corrugation (www.fhwa.dot.gov)

Depressions

Depressions are small, localized and bowl shaped areas that may include cracking which cause roughness and allow water to collect. Localized consolidation or movement of the supporting layers under the surface course due to instability is the major cause of depressions ^[5].



Figure 14. Depression (www.pavementinteractive.org)

Swell

Swell is a localized hump on the pavement surface caused by an expansion of the supporting layers under the surface course or the subgrade. Moisture and subgrade with highly plastic clay are the major causes of expansion ^[5].



Figure 15. Swelling (www.pavemanpro.com)

C. Disintegration

Disintegration is a progressive breaking up of pavement into small and loose pieces. The most common types of disintegration are potholes and patches ^[5].

Potholes

Potholes are bowl-shaped holes similar to depressions. The failure starts with a small fragment at the top of layer and it will progress downward into the lower layers of the pavement over time. Potholes are caused by moisture (area of poor drainage), pavement disintegration under traffic loading and due to inadequate strength in one or more layers of the pavement ^[5].



Figure 16. Potholes ^[10]

Patches

Patches are used to repair defects which are applied on a portion of pavement. However, patch failure can lead to a more widespread failure of the surrounding pavement ^[5]. Patches may be caused by inadequate cleaning or inadequate tack coat before placement of upper layers, seepage of water or moisture and weak or loose layer ^[15].



Figure 17. Patching (NET Consult Consulting Engineers and Architects Plc)

D. Surface defects

Surface defects are the major type of pavement distress which occurred in the surface layer^[5]. The most common types of surface distress could be described as below.

Raveling

Raveling is the loss of material from the pavement surface due to insufficient adhesion between the asphalt cement and aggregate. Raveling can be accelerated by traffic and freezing weather^[5].



Figure 18. Raveling^[5]

Bleeding

Bleeding is the presence of excess asphalt on the road surface which creates patches of asphalt cement. It reduce the skid-resistance of a pavement, and it can become very slippery when wet, creating a safety hazard. Excessively high asphalt cement content in the mix, asphalt cement with too low a viscosity (too flowable), too heavy a prime or tack coat and improperly applied seal coat are the causes of bleeding. Bleeding occurs more often in hot weather when the asphalt cement is less viscous (more flowable) and the traffic forces the asphalt to the surface^[5].



Figure 19. Bleeding^[14]

Polishing

Polishing is the presence of aggregate with either small or no rough or angular aggregate particles extending above the asphalt binder due to heavy traffic movement. Inadequate resistance to polishing of surface aggregates, use of naturally smooth uncrushed aggregates, inadequate cleaning or inadequate tack coat before placement of upper layers, seepage of water through asphalt and weak layer are the possible causes of polishing ^[15].

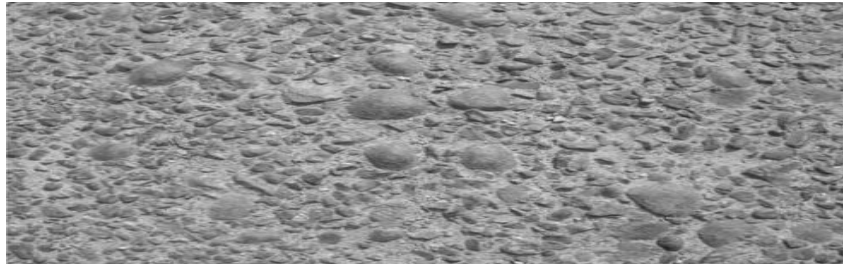


Figure 20. Polishing ^[11]

2.4 Strength of road pavement

The strength of a road pavement is inversely related with its maximum vertical deflection under a known dynamic load and the stiffness of asphalt surfacing is changed with temperature. Hence, the pavement surface temperature recorded at the time of deflection measurement should correct to a standard temperature of 35°C before interpreting the reading deflection ^[12].

The benchmark of deflection based on falling weight deflectometer for various pavement types is developed in South Africa as shown in table 1 ^[16].

Table 1. Deflection bowl parameter structural condition rating criteria ^[16]

	Structural condition rating	Deflection bowl parameters				
		D ₀ (µm)	RoC (m)	BLI (µm)	MLI (µm)	LLI (µm)
Granular Base	Sound	<500	>100	<200	<100	<50
	Warning	500-750	50-100	200-400	100-200	50-100
	Severe	>750	<50	>400	>200	>100
Cementitious Base	Sound	<200	>150	<100	<50	<40
	Warning	200-400	80-150	100-300	50-100	40-80
	Severe	>400	<80	>300	>100	>80
Bituminous Base	Sound	<400	>250	<150	<100	<50
	Warning	400-600	100-250	150-300	100-150	50-80
	Severe	>600	<100	>300	>150	>80

Studies have been made that relate FWD to Benkelman Beam Deflections ^[17].

$$BB = 1.61 * FWD$$

Where; BB = Benkelman Beam Deflection

FWD = FWD Deflection

2.5 Road pavement surface condition

Surface damage index (Is) is a global visual index used to quantify and rate the failure of pavement; and evaluate the condition of the road. It is a function of severity and extent of the damage along the road. ERA pavement rehabilitation and asphalt overlay manual, 2002, classify the type and severity of damage as shown in Table 2 and 3. The manual also recommend 500m interval to calculate the extent of damage^[18].

Table 2. Level of Severity of Type A damage^[18]

Severity \ Damage	1	2	3
Deformation rutting	Perceptible to user but small $f < 2$ cm	Severe deformations, localised subsidence or rutting $2 \leq f \leq 4$ cm	Deformation severely affecting safety or travel time $f \geq 4$ cm
Cracking	Hair line cracks in wheel tracks or centerline	Open and / or branching cracks	Markedly branched and/or wide open cracks: edges sometimes damaged
Crazing	Fine crazing with no loss of materials large mesh (> 50 cm)	Tighter crazing (< 50 cm) sometimes accompanied by loss of materials, stripping, and incipient potholes	Very open crazing forming blocks (< 20 cm), sometimes accompanied by loss of materials
Patching and Repair	<input type="checkbox"/> Either rebuilding of part or all of pavement	Surface work related to type A defects	
	<input type="checkbox"/> Or surface work related to type B defects		

Table 3. Level of Severity of Type B damage^[18]

Severity \ Damage	1	2	3
Longitudinal joint crack	Hair line isolated	<ul style="list-style-type: none"> Wide (1 cm or more) without stripping or Hair line & branching 	<ul style="list-style-type: none"> Wide with spalling of edges or Wide and branching
Pothole	<ul style="list-style-type: none"> Number < 5 Dia, not more than 30 cm 	5 to 10 < 5 or Dia. 30 cm Dia. 100 cm	> 10 5 to 10 or Dia. 30 cm Dia. 100 cm
	Per 100 m of pavement		
Movement of material Ravelling, fretting, bleeding, etc.	Localised. Roadbase not visible	Continuous or localised but roadbase visible	Continuous and roadbase visible
	Localised.	Continuous in one wheel track	Continuous and "marked" in one wheel track

Calculation of surface damage index is based on the severity and extent of pavement failures from the following three damage groups; and the flow chart of determination of damage index which is shown in Figure 21^[18].

- Cracking and Crazing (Cracking Index, I_f)
- Deformation and Rutting (Deformation Index, I_d)
- Repairs

The result from calculation of surface damage index is classified in to three categories; ^[17]

1. $I_s = 1$ and 2, represent good surface condition
2. $I_s = 3$ and 4, represent intermediate (fair) surface condition
3. $I_s = 5, 6,$ and 7, represent very poor surface condition

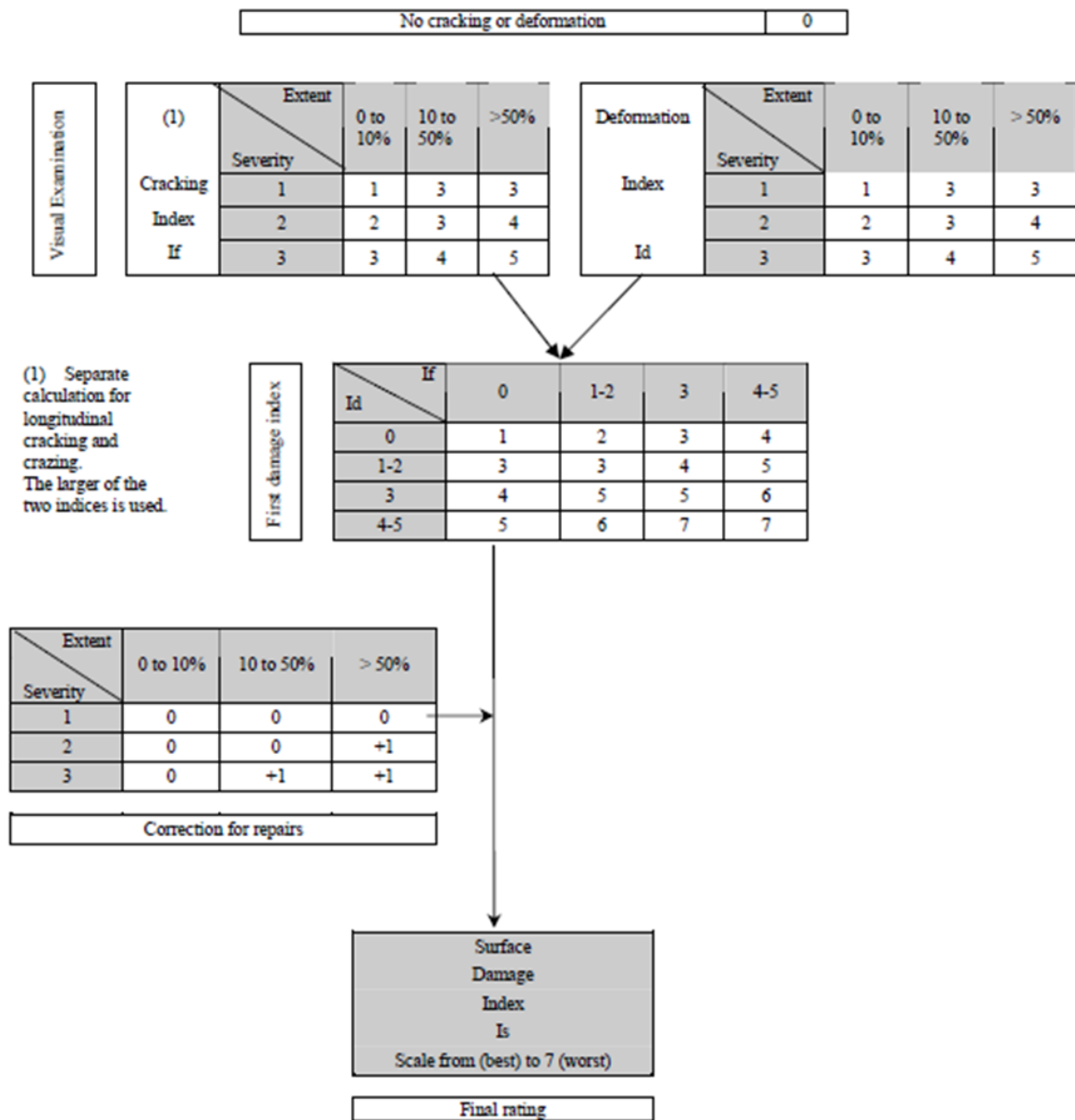


Figure 21. Flow Chart of determination of damage index ^[18]

2.6 Different traffic loading condition experience in different countries

2.6.1. Ethiopia

According to National Bank of Ethiopia's annual report, 2013/2014, the average amount of export from 1999/00 to 2013/14 is only 44% of the import goods and services as shown in Table 4.

Table 4. External Trade of Ethiopia (National Bank of Ethiopia Annual Report, 2013/2014)

Year	Export of goods and services in Mn. USD	Growth in %	Import of goods and services in Mn. USD	Growth in %	Trade Balance (Export - Import)	Export / Import in %
1999/00	984.0	-	1,959.8	-	- 975.8	50
2000/01	979.1	-0.50	1,936.4	-1.19	- 957.3	51
2001/02	982.7	0.37	2,073.1	7.06	- 1,090.4	47
2002/03	1,139.6	15.97	2,346.7	13.20	- 1,207.1	49
2003/04	1,519.4	33.33	3,267.9	39.26	- 1,748.5	46
2004/05	1,870.5	23.11	4,352.7	33.20	- 2,482.2	43
2005/06	2,156.9	15.31	5,431.8	24.79	- 3,274.9	40
2006/07	2,545.4	18.01	6,332.7	16.59	- 3,787.3	40
2007/08	3,128.0	22.89	8,313.1	31.27	- 5,185.1	38
2008/09	3,399.2	8.67	9,292.5	11.78	- 5,893.3	37
2009/10	4,050.4	19.16	9,858.5	6.09	- 5,808.1	41
2010/11	5,343.1	31.92	10,161.2	3.07	- 4,818.1	53
2011/12	5,971.7	11.76	13,805.9	35.87	- 7,834.2	43
2012/13	5,978.5	0.11	13,864.2	0.42	- 7,885.7	43
2013/14	6,482.9	8.44	16,335.7	17.83	- 9,852.8	40
Average	3,102.1	15	7,288.8	17	- 4,186.7	44

However, without design the road with legal axle load limit and implementation of axle load control stations to control the excess load, any kind of consideration is not applied during design, construction and service stage of road to handle the load difference.

Furthermore, according to Ethiopian Revenues and Customs Authority's goods flow data between Addis Ababa and Djibouti from 2010 to 2014, the average exported material is only 12% of the average imported material as shown in Table 5.

Table 5. Material Flow between Ethiopia and Djibouti (Ethiopian Revenues and Customs Authority's good flows data)

Year	Import goods gross weight (tonnes)	Growth (%)	Export goods gross weight (tonnes)	Growth (%)	Trade Balance (Export - Import)	Export / Import (%)
2010	7,107,537.82		812,453.52		-6,295,084.29	11
2011	7,321,710.00	3	844,774.92	4	-6,476,935.09	12
2012	8,509,535.64	16	991,731.18	17	-7,517,804.46	12
2013	7,382,383.90	-13	1,073,498.86	8	-6,308,885.04	15
2014	10,094,582.39	37	1,253,887.74	17	-8,840,694.65	12
Average	8,083,149.95	11	995,269.24	12	-7,087,880.71	12

2.6.2. South Africa

Road N3 is the main road in South Africa which found between the port of Durban on the east coast and industrial center in capital Johannesburg. In the city of Pietermaritzburg, 16 km long road section where the road consists of a highway section with three lanes in each direction. Along the route, reinforced concrete pavement is used for the heavily congested lane and for the other two lanes, asphalt concrete is used ^[19].

2.6.3. Sweden

On Swedish motorway the majority of traffic is used the right lane and the left lane is used mainly for overtaking and almost only by light traffic. Hence the traffic loading conditions are very different between the two lanes. To handle this difference, a combination pavement with a concrete construction in the right hand side lane and a bituminous construction in the left hand side lane is implemented. Subsequently, the heavily trafficked lane with concrete construction gives service for more than 20 years without any maintenance and during the service period it carry 95 million vehicles out of which 9 million were heavy vehicles ^[19].

2.6.4. German

The motorway ring around Cologne in North Rhine-Westphalia (NRW) in Germany, carry 150, 000 vehicles per day out of which 12-18% is heavy vehicles. In recent years the number of heavy vehicles is increased and it is higher on the highway right-hand lane. Following, the rising volume of traffic, the road administration in NRW chose to use concrete in the heavily trafficked right lane and keep the asphalt in the left lane. Under this condition the heavily trafficked lane gives service for 20 years without a single lane plate replacement ^[19].

2.6.5. USA

In eastern Oregon, traffic load is high on the right lane of motorways and the axle load difference between the lanes caused failures on heavily trafficked lane much faster whereas after several years of traffic the left lane is still in good condition. Hence, FHWA and Oregon DOT develop cost effective coating and build the right lane in concrete and the left lane in asphalt in 1989^[19].

2.7 Axle load survey for pavement design

Axle load survey must be carried out to determine the axle load distribution of a sample of the heavy vehicles using the road as per vehicle classification under Table 6. If significant differences between the two streams /lanes/ occurs where the vehicles traveling one way are heavily loaded but are empty on the return journey, the results from the more heavily trafficked lane should be used when converting volumes to ESA for pavement design^[12].

2.8 Axle configuration

The information about axle configuration of the vehicle is important during the time of axle load survey. The classification system of axle configuration is based on a code, each axle is represented by '1' or '2' depending on the number of wheels (tyres) at each end of the axle. To separate the front and rear axles, a decimal point is placed between the codes. Tandem and Tridem axles are also represented by recording these codes directly after each other without any decimal point. A trailer and Semi-trailers or articulated vehicles can be denoted by a '+' and a '-' sign respectively^[20].

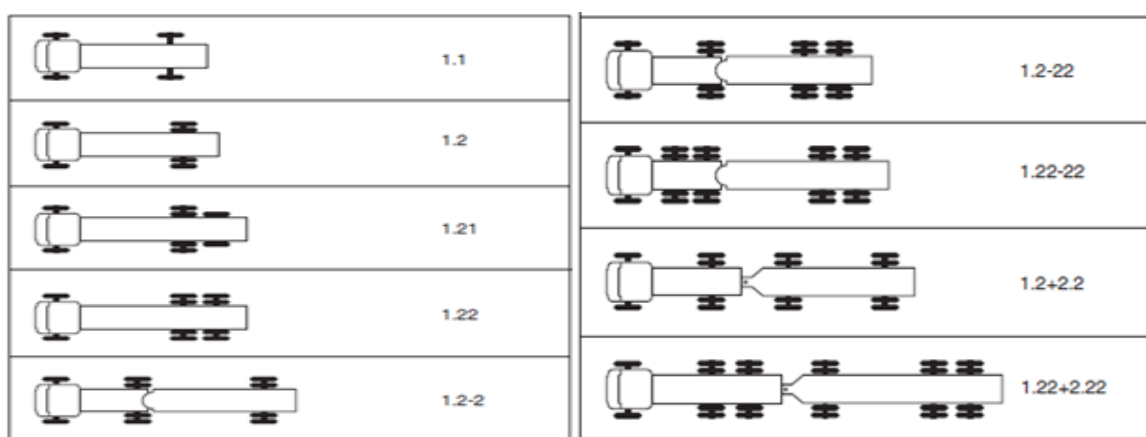


Figure 22. Axle Configuration^[20]

2.9 Traffic volume and vehicle classification

One of the fundamental measures of traffic on a road system is the volume of traffic. Estimation of initial traffic volumes is the first step to determine the total traffic over the

design life of the road. The estimate should be the Average Annual Daily Traffic (AADT) which is the total yearly traffic volume in both directions divided by the number of days in the year (365) ^[12].

According to ERA Pavement Design Manual Volume 1: Flexible Pavement, 2002, vehicles are classified in to five major classes as shown in Table 6. Vehicle classification is very important for traffic volume and equivalent axle loads evaluation.

Table 6. Vehicle Classification (ERA Pavement Design Manual Volume 1: Flexible Pavement, 2002)

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

2.10 Damaging effect of overloading on pavement

According to AASHTO (American Association of State Highway and Transport Officials) Road test between 1956 and 1960, the damaging effect of overloaded vehicle is exponential as shown below and it compare the damaging effect of actual axle load (P) with the standard axle load of 8.2 tonnes (80 KN) with an average value of n = 4.2 ^[21].

$$Equivalency\ Factor\ F = \left(\frac{Actual\ axle\ load\ (P\ ton)}{Standard\ axle\ load\ (8,2\ ton)} \right)^n$$

The result of Equivalent Factor (EF) using the above formula is used to convert all axle loads and vehicle configurations into an equivalent number of standard axles. For example, if the overloaded vehicle carrying twice the legal load and the legal load is 18 tonnes, the equivalent factor will be $(36/18)4.2 = 18.4$. This means the damaging effect of this overloaded vehicle is 18.4 times of the damaging effect caused by the legal load ^[21].

According to Ethiopian Roads Authority Vehicle Weight and Size Control Team Annual Report, the percentage of overloaded vehicles is decreased as shown in Table 7 and 8 from year 2004/5 to 2014/15.

Table 7. Overloading History at Awash Vehicle Weight and Size Control Station

Year	2004 /5	2005 /6	2006 /7	2007 /8	2008 /9	2009 /10	2010 /11	2011 /12	2012 /13	2013 /14	2014 /15
Overloading (%)	37.5	46.0	45.6	39.3	32.2	16.8	13.5	9.5	5.0	4.2	5.2

Table 8. Overloading History at Modjo Vehicle Weight and Size Control Station

Year	2004 /5	2005 /6	2006 /7	2007 /8	2008 /9	2009 /10	2010 /11	2011 /12	2012 /13	2013 /14	2014 /15
Overloading (%)	38.0	17.0	29.9	33.3	41.0	1.5	6.3	3.7	6.2	6.1	8.0

*2014/2015 data only include from July 1, 2014 to September 30, 2015

Daniel Legesse, 2013, has been estimate the percentage of overloading at different overload control stations based on one year axle load survey data from the stations and he found that the percentage of overloading is 11.2% and 4.8% at Awash and Modjo vehicle weight and size control stations respectively.

The axle load management at Holeta and Modjo vehicle weight and size control station has been studied by Biniyam T. 2015. Biniyam has conducted axle load survey for seven consecutive days with three times repetition in different months on both Holeta and Modjo vehicle weight and size control station; and he found that the actual percentage of overloading calculated from the collected data is not similar with the percentage of overloading taken from the stations. According to Biniyam T. 2015, the percentage of overloading is 69.3 and 45.3% at Holeta and Modjo vehicle weight and size control station respectively. However, the percentage of overloading from the stations data is 4% and 7% at Holeta and Modjo vehicle weight and size control station respectively.

Addis Mehari, 2015, has also estimated the percentage of overloading at Awash vehicle weight and size control station based on the collected axle load survey data for one day afternoon and one day morning in two days interval and he found that the percentage of overloading is 48% and 56% of this overloading is lies on the margin (10.1 – 12 tonnes). According to Addis M. 2015, this 48% of overloading reduce the service life of the pavement from 20 years design life to 11 years and it requires 12.2cm overlay thickness to carry additional load caused by overloading.

2.11 Overloading control system

To protect the road network from premature failures due to overloading, efficient and effective overloading control system is required.

Ethiopian Roads Authority (ERA) has established ten static Vehicle Weight and Size Control Stations (Modjo, Awash, Dengego, Shashemene, Holleta, Alemgena, Sululta, Jimma, Kombolcha and Sendafa Vehicle Weight and Size Control Station) and two mobile weighbridges to protect the road infrastructure assets from failure caused by overloading before their design life. The individual axle load of each heavy vehicle is recorded and

each weighbridge operates full time, 24 hours a day and 7 days a week. The Federal Democratic Republic of Ethiopia Ministry of Trade calibrates the weighbridges every year.

The vehicle weight and size control system in Ethiopia is carried out based on the axle load control system. Gross Vehicle Weight system is applied only for vehicles with axle configuration 1.2. Because, due to the problem of designing this type of vehicles, the higher portion of the load is carried by the rear axle ^[22].

Axle load limit

Most countries have axle load limit to control overloading and person who overloads an axle of a vehicle shall punish as per the law and regulation of the country. The axle load limit of some countries is summarized as shown in Table 9.

Table 9. Maximum Permissible Axle Load Limits ^{[23],[24]}

Type of Axle /Axle Group	Tyres	Burindi	Kenya	Rwanda	Tanzania	Uganda	COMESA /SADC	Agreed EAC Limits	US	EU Countries	Ethiopia
Single steering drive operated	2	10	8	10	8	8	8	8		8	8
Single steering drawbar controlled	4	10	8	10	9	8	-	-	-	8	10
Single non steering	2	10	7.5	10	8	NS	8	8	9.1	10	8
Singe non steering	4	10	10	10	10	10	10	10	-	11.5	10
Tandem non steering	8	16	16	16	18	16	18	18	14.5	11-20	17

Note: each axle load limit in the above table is expressed in tonnes

2.11.1 Operational allowance/tolerance

Scales do not always give a 100 percent accurate reading, operator may make small error during the loading of the vehicles and law does not concern itself with trifles. Hence, most countries allow a 5 percent tolerance on both axle loads and total vehicle/combination mass ^[25].

For the harmonization of vehicle overload control in the East Africa Community, the partner states (Kenya, Tanzania, Burundi, Rwanda and Uganda) agreed to apply the

principles of 5% tolerance on axle weight and not to apply any percentage of tolerance for maximum gross vehicle weight ^[23].

2.11.2 Systems for collecting overloading charges

There are two types of overloading charge collecting systems, criminalized fines and decriminalized fee. During criminalized system, the overloading charge is collected by court and it will transfer to general budget of the country. Whereas, in case of decriminalized system, the overloading charge is collected by the road agency at the weighbridge station and it will transfer to road fund ^[23].

According to Japan International Cooperation Agency (JICA) Padeco Co., Ltd. 2011, Study for the Harmonization of Vehicle Overload Control in the East African Community (EAC), overloading should be decriminalized and the total amount of overloading charges should cover the cost of maintenance to repair damage attributable to overloaded vehicles.

The JICA Study Team recommends decriminalization of overloading due to the following reasons;

- to secure revenues from overloading charges for the road maintenance budget.
- to avoid the long delays suffered by prosecuting offenders judicially
- to secure an immediate, administratively effected sanction
- to avoid encouraging corruption caused by complicated criminal procedures

The JICA Study Team also recommends the following principles to set the overloading charges;

- overloading charges should cover road damage cost
- road damage cost is not only routine and periodic maintenance costs but also rehabilitation and reconstruction costs to cover the road damage.

From the EAC countries, Tanzania has experience on decriminalized overloading and the overloading charge paid to the road authority rather than the public treasury, while the others are imposed fines. Zimbabwe is often cited as a good example for decriminalization of vehicle overloading and the introduction of administrative adjudication procedures to deal with infringements led to more effective control ^[23].

Comparison of the maximum level of fees/fines and systems for vehicle overloading in the five partner states is shown in Table 10.

Table 10. Comparison of the Maximum Level of Fees/Fines ^[23]

Country	USD	National Currency
Kenya	5,000	400,000
Tanzania	35,000	-
Burundi	2	2000
Rwanda	300	180000
Uganda	250	600000

Source: JICA Study Team

However, Ethiopia has not fixed overload charge system to penalize overloaded vehicles and the penalty system for overload charge is subjective.

2.11.3 Corrections for excess load

According to Pinard, 2010, all overloaded vehicles that exceed the permitted tolerance should be forbidden to travel further until the load has been adjusted. This should be the standard practice at all weighbridges. The level to which the load is adjusted must also be standardized. In some cases it is required that the load be adjusted back to the legal limits, i.e. no tolerance is applied. In other cases it is required that the load be adjusted to within the legal limit plus the tolerance. It should also be standard practice that no loads are allowed to be off-loaded onto the ground at a weighbridge, but should be transferred to another vehicle. Every weighing facility should be able to notify the operator of a vehicle that his vehicle is overloaded and that the vehicle will not be permitted to travel any further unless the load is adjusted ^[25].

In Ethiopia overloaded vehicles should be offload or rearrange the excess load before travel further until it becomes as per the legal limit and the overload charge should be paid in the nearest court ^[22]. According to the Road Fund Establishment Proclamation in Ethiopia, overloading charge is the one source of revenue for road fund. However, in the current scenario the overloading charge is used by the Wereda's of the court. If the commodity is sealed or with container, the load is not predictable and it is the first time, the driver gets the written permission from ERA Road Network Management Directorate Director to pass without offloading/rearrangement ^[22].

2.11.4 Service mechanism and handling of queuing system

Queues are awaiting line which formed when customers wait to get service due to the number of customers exceed the number of servers available; or the facility doesn't work efficiently or takes more than the time prescribed to service a customer ^[26].

Queuing system

Queuing system is defined by the following major input parameters or components namely; mean arrival rate, mean service rate, the number of servers and queue discipline.

The component of basic queuing system is shown in Figure 23 ^[27].

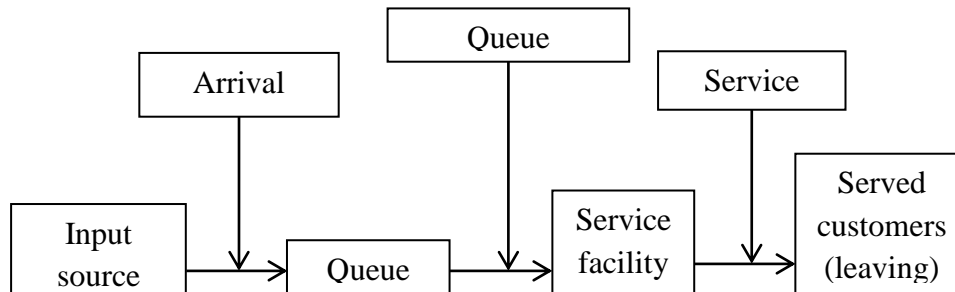


Figure 23. Components of a basic queuing system ^[27]

- Mean Arrival Rate (λ)
Arrival rate is rate which vehicles arrive at a service facility and it is expressed in flow (vehicle/hr).
- Mean Service Rate (μ)
Service rate is rate which vehicles depart from a service facility and it is expressed in flow (vehicle/hr).
- Number of Servers
The quantity of servers which found in the service station and the manner they work (parallel or series) has to be specified.
- Queuing Discipline
Queuing Discipline is the process of selecting customers for service. There are five major queuing disciplines namely; first in first out (FIFO) or first-come-first served (FCFS) discipline, first in last out (FILO) or last come first served (LCFS) discipline, served in random order (SIRO) discipline, priority scheduling discipline and Processor (time) Sharing discipline. The common way of queuing discipline is first in first out (FIFO) or first-come-first served (FCFS) discipline.

3. MATERIAL AND METHODS

The thesis has been conducted based on the following three phases which are road segment selection, data collection and data analysis.

3.1 Road segment selection

Adama-Mile road segment (see Figure 24) which is around 433Km was selected from Addis Ababa - Djibouti route as the route is the main import-export corridor in Ethiopia and there is imbalance material flow between Addis Ababa and Djibouti. The selected section, Adama-Mile was classified into Adama-Awash and Awash-Mile road segments to analyses the data based on the following two reasons:

- To analyze and compare the management of load balance and its impact on pavement conditions between the two road segments. Since, the imbalance load along Awash-Mille road segment is relatively higher than Adama-Awash road segment.
- To analyze the efficiency of Awash Vehicle and Weight Control Station as it is found between the two road segments.

Furthermore, Awash and Modjo Vehicle Weight and Size Control Stations are selected for the data collection purpose as the stations are along Addis Ababa - Djibouti route.

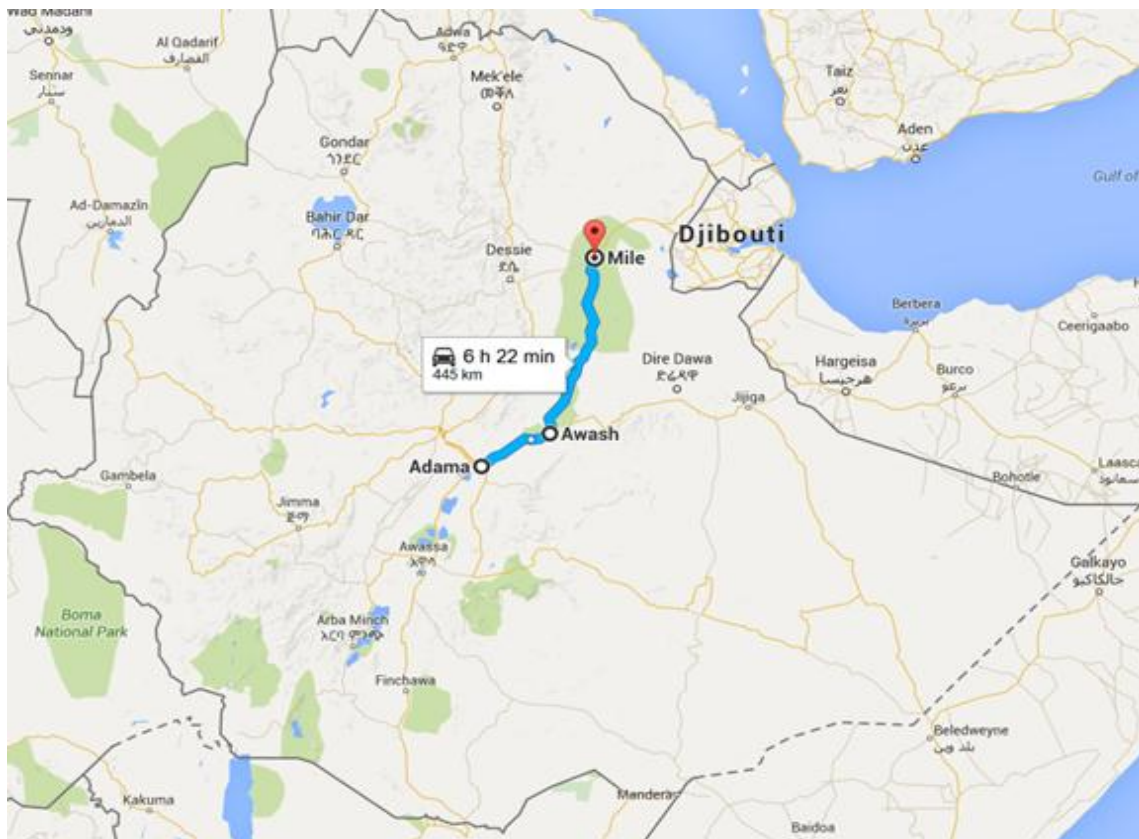


Figure 24. Selected Road Segment (Map Data@2016 Google, ORION-ME)



Figure 25. Sample Pictures (A represent Djibouti-Addis Ababa lane and B is vice versa)

3.2 Data collection

Primary data has been gathered through observation, measurement and questionnaire which is needed to know and investigate the actual conditions. Furthermore, secondary data which is listed under section 3.2.3 has also been collected from relevant private and governmental offices.

3.2.1 Field observation and measurement

Axle load survey

Axle load survey was conducted in July, October and November at Awash Vehicle Weight and Size Control Stations; and August, September and October at Modjo Vehicle Weight and Size Control Stations for seven days on each month and stations. To collect axle load survey data, data collection form which is attached as annex 1 was prepared.



Figure 26. Vehicles under Examination at Awash and Modjo Control Stations

Overload charge and corrections on excess load

The overload charge paid by penalized vehicles and the corrections taken on the excess load was collected together with the axle load survey. The summary of the collected data on overload charge and corrections on excess load at the selected axle load control stations is attached as annex 2.

Number of loaded and empty vehicles along Adama -Awash road segment (Export lane)

Number of loaded and empty vehicles for truck and trailers along the road segment was counted on March 30 and 31, 2016.

Pavement condition survey

Pavement condition survey has been carried out on December 12 and 13, 2015 from Adama to Awash Arba, which is around 137 km. During the time of survey, measurement on rutting and potholes on more damaged sections has been taken due to time and cost constraint.



Figure 27. Rut Depth Measurement during Pavement Condition Survey

Deflection test

The pavement deflection test was collected at the same time with visual pavement condition survey using Benkelman beam. The truck used to measure deflection has dual rear wheels and loaded 8.2 tonnes which is a standard rear axle load recommended for deflection test.



Figure 28. Deflection Data Collection

It should be noted that the deflection test was not carried out along all stretch of the selected road segment due to time and cost constraint. The deflection test along Awash-Awash Arba road segment was carried out continuously per 500m interval. However, the deflection measurement from Adama-Awash road segment was carried out on the most damaged sections since the damaged sections are long.

Queue survey (arrival and service time of vehicles)

The arrival and service time of vehicles were collected from December 20-26, 2015 at Awash Vehicle Weight and Size Control Stations and from August 25-29, 2015 at Modjo Vehicle Weight and Size Control Stations.



Figure 29. Vehicles on Queue at Awash and Modjo Control Stations

3.2.2 Questionnaire

Questionnaire was prepared for four target groups namely, pavement Engineers, drivers, vehicle weight and size control team; and control station staff. To collect response for the questionnaires, nonprobability sampling method and census method of data collection was used. Nonprobability sampling method was used for pavement engineers and drivers since the population size is not known; and census method of data collection was used for vehicle weight and size control station staffs and team since the population size is known and it is small. A total of 92 individuals were participated in the survey which includes 35 pavement engineers, 33 drivers and 24 vehicle weight and size control station staffs and team. The sample questionnaire is attached as annex 3.

3.2.3 Secondary data

Table 11. Type and Source of Secondary Data

Collected Data	Source
Number of loaded and empty vehicles along Awash- Mille road segment	Net Consulting Engineers and Architects P.L.C
Axle load survey data for empty vehicles along Awash-Mille Road Segment	
Detail condition survey data along Awash-Mille road	
Subgrade soil extension and drainage data	
Axle load survey data for empty vehicles along Adama - Awash road segment	Lidet Consulting Engineers P.L.C for Export Lane
Historical traffic count data, 2015	Ethiopian Roads Authority (ERA), Road Asset Directorate
Previous Engineering design report	Ethiopian Roads Authority (ERA), Engineering Procurement Directorate
Rehabilitation cost	

3.3 Data analysis

Data Analysis is the major process to carry out research result. Hence, the collected data was analyzed for both lanes separately based on the following methods which are shown below to address the specific objectives and to come to the possible solutions.

Stages of Data Analysis	Methods used	Results
Calculate Equivalent Standard Axles (ESAs) and Actual Pavement Service Life	<p>AASHTO Fourth Power Law</p> <p>i. $ef = (L/8.16)^n$3.1</p> <p>Where; ef = number of equivalent standard axles L = axle load (tonnes) n = damage exponent (n=4.5)</p> <p>ii. <i>Actual pavement service life per vehicle =</i> $\frac{\text{Design Life}}{\text{Actual ESAs}}$3.2^[28]</p> <p>Where; Actual Service Life = the service period of pavement under actual ESAs Design Life = The expected service life in the design stage (20 years since the selected road segment is trunk road. Actual ESAs = Equivalent Standard Axles per vehicle</p> <p>iii. <i>Actual pavement service life for combined traffic =</i> $\sum_{m=1}^n (\text{mean actual pavement service life per vehicle type} * \text{percentage composition of vehicle type})$3.3^[28]</p> <p>iv. Compare the results from the two lanes</p>	Impact of imbalance in goods flows on pavement service life
Analyze pavement surface condition	Surface Damage Index (Is)	
Analyze deflection test result	Benchmark of deflection developed in south Africa.	
Identify the cause of existing pavement failures and compare the results from the two lanes	<p>Nature of existing failure and their possible causes:</p> <p>To find the pure impact of imbalance in goods flows, the selected road segment was classified in to four groups based on surface damage index result, drainage and subgrade soil extension.</p>	Impact of imbalance in goods flows on pavement conditions

Stages of Data Analysis	Methods used	Results
	<ul style="list-style-type: none"> • Sections which have similar failures on both lane • Sections which have high failures on the import lane • Sections which have high failures on the export lane • Sections under good drainage and subgrade area 	
Identify load associated failures along the road segment before and after the control station and compare the results	Descriptive statistics	Efficiency of vehicle weight and size control station
Assess the overall extent of overloading, penalty and corrections for excess load	Descriptive statistics	
Evaluate handling of queuing system at Vehicle Weight and Size Control Station	Queuing Model for service facility with one server (M/M/1) model and Little's law	
Analyze questionnaire	Descriptive Statistics	

4. RESULTS

The collected primary and secondary data was analyzed using the above methodology and the following results were found.

4.1 Impact of load imbalance on pavement service life

i. Percentage of overloading per lane

Along Awash-Mille road segment, 15% of heavy vehicles which are running on the export lane and 92% of heavy vehicles which are running on the import lane is above the legal load limit; and along Adama Awash road segment, 17% of heavy vehicles which are running on the export lane and 92% of heavy vehicles which are running on the import lane is above the legal load limit. It was also found out that 84 and 82% of running vehicles on the export lane is empty along Awash-Mille and Adama-Awash road segment, respectively.

ii. Mean Equivalent Standard Axles (ESAs)

The result from calculation of Mean Equivalent Standard Axles (ESAs) per vehicle types and road segments shows the following;

Awash - Mille road segment

- The Mean ESAs of truck and trailers is 15.3 on the import lane and 2.9 on the export lane which means the Mean ESAs on the import lane is 5.3 times of the export lane.

Adama-Awash road segment

- The Mean ESAs of truck and trailers is 15.4 on the import lane and 3.2 on the export lane which means the Mean ESAs on the import lane is 4.8 times of the export lane.

The summary of Mean ESAs per lane and road segment is shown in Figure 30.

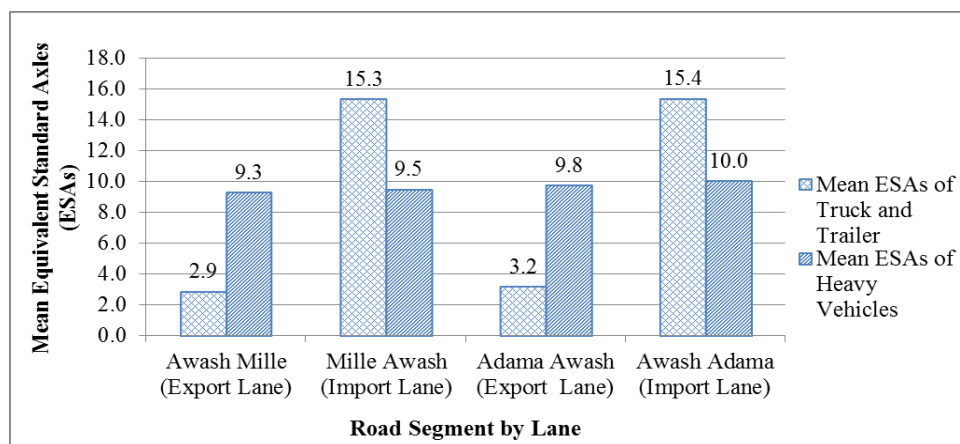


Figure 30. Mean Equivalent Standard Axles (ESAs) per Lane and Road Segment

iii. Actual pavement service life

The actual service life of the pavement is decreased on the import lane and increased on the export lane.

Awash - Mille road segment

- The actual service life of the export lane is 31 years and the import lane is 6 years whereas the road is designed for 20 years. It indicates that the service life of the export lane is increased by 11 years (55%) and the actual service life of the import lane is reduced by 14 years (71%).

Adama - Awash road segment

- The actual service life of the export lane is 22 years and the import lane is 12 years whereas the road is designed for 20 years. It indicates that the service life of the export lane is increased by 2 years (9%) and the actual service life of the import lane is reduced by 8 years (38%).

The summary of actual pavement service life per lane and road segment is shown in Figure 31.

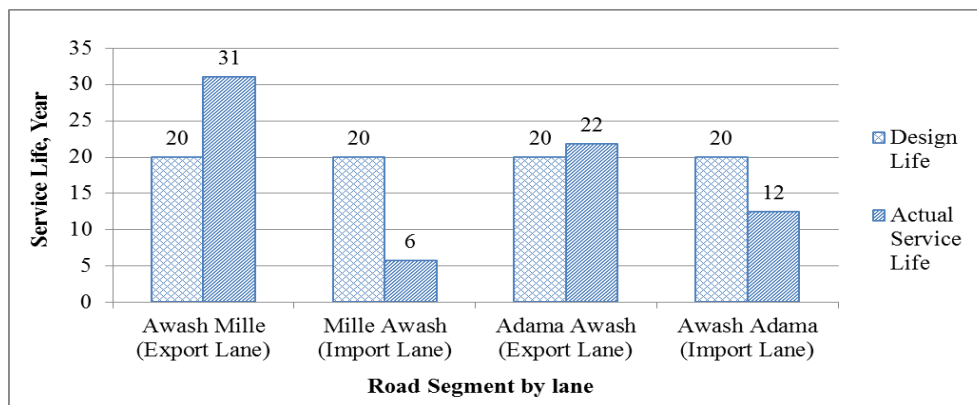


Figure 31. Design Vs Actual Service Life of Pavement per Lane and Road Segment

4.2 Impact of load imbalance on pavement conditions

i. Pavement surface condition

To identify the pavement surface condition along Awash-Mille road segment, surface damage index per 500m road length for both lanes was calculated separately and the result is shown in Figure 32-36. The result of surface damage index 1 and 2 represent good surface condition, 3 and 4 represent intermediate (fair) surface condition and; 5, 6, and 7, represent very poor surface condition.

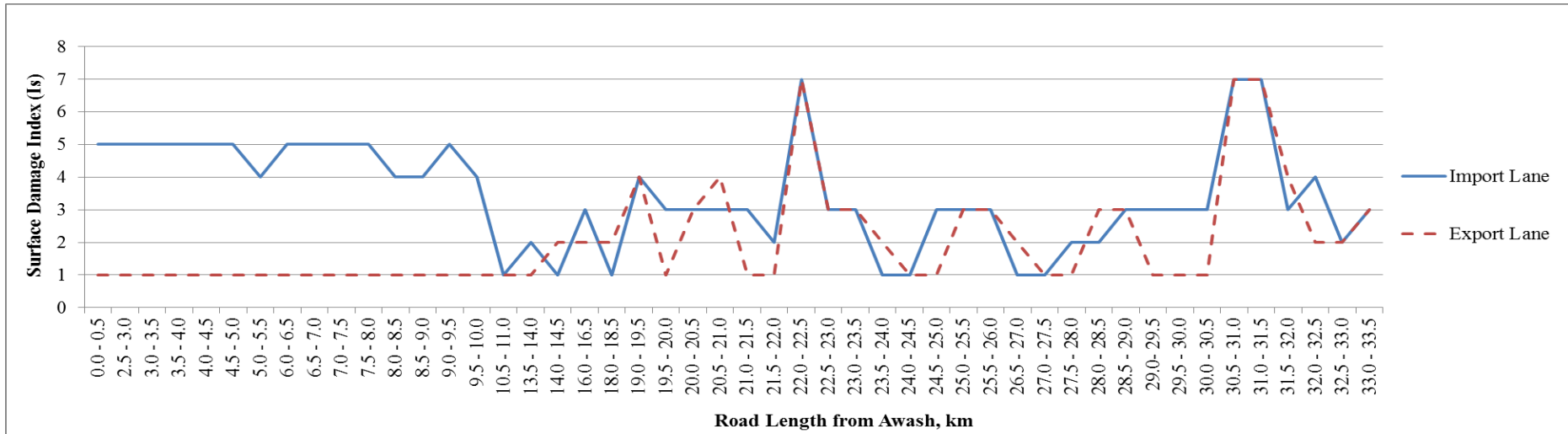


Figure 32. Surface Damage Index per lane (0.0-33.5 km)

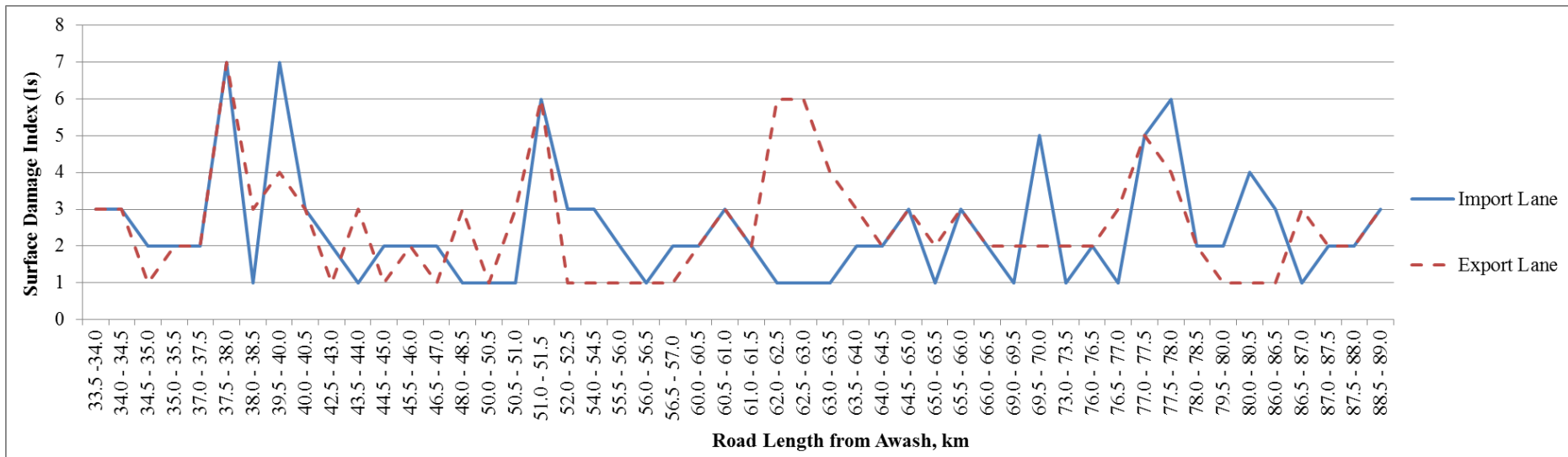


Figure 33. Surface Damage Index per lane (33.5-89.0 km)

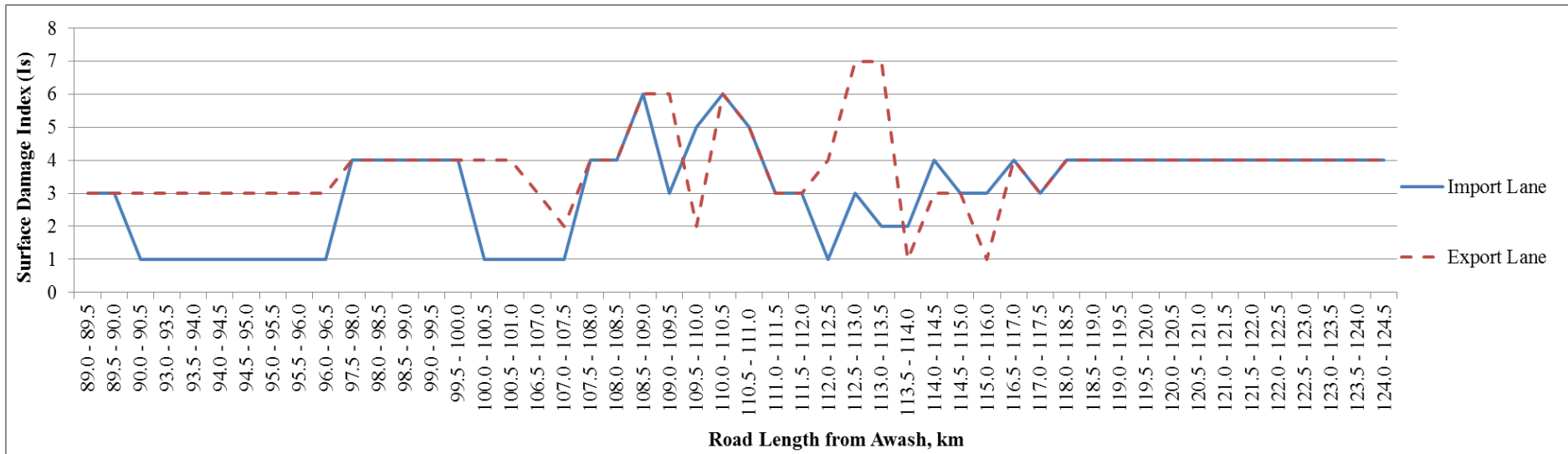


Figure 34. Surface Damage Index per lane (89.0 – 124.5 km)

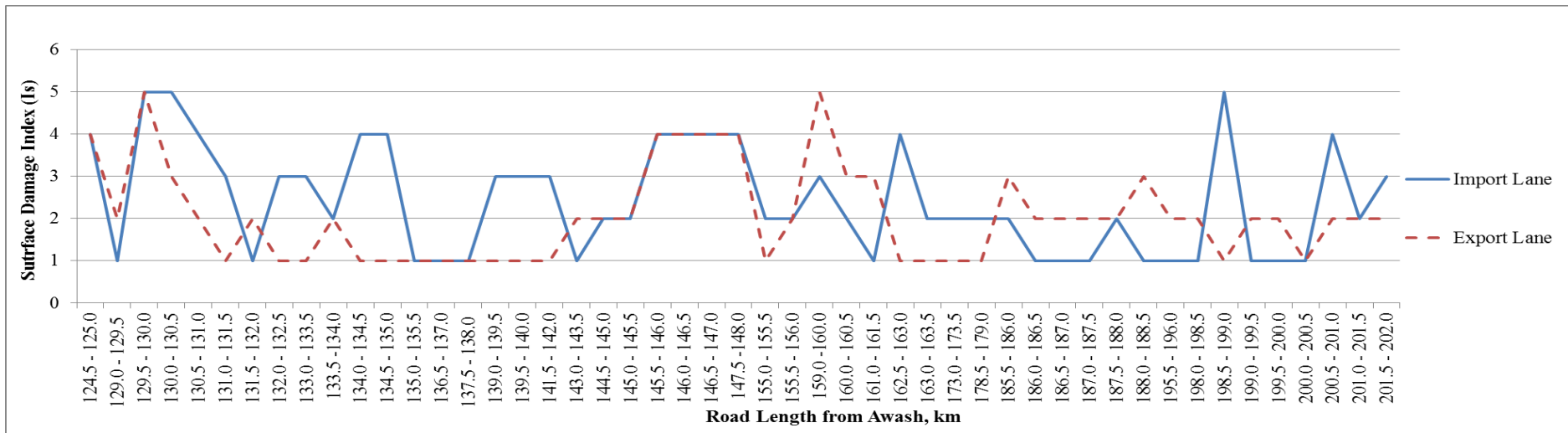


Figure 35. Surface Damage Index per lane (124.5 – 202.0 km)

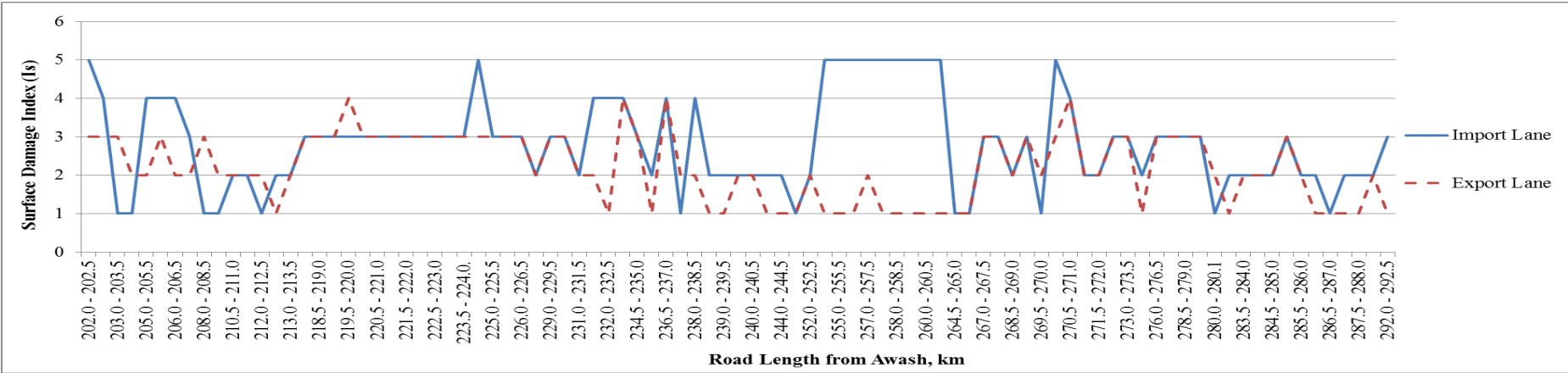


Figure 36. Surface Damage Index per lane (202.0-292.5 km)

The above result from calculation of surface damage index shows that 55% of the import lane and 45% of the export lane along Awash-Mille road segment is under fair and poor surface condition. The summary of pavement surface condition is shown in Figure 37.

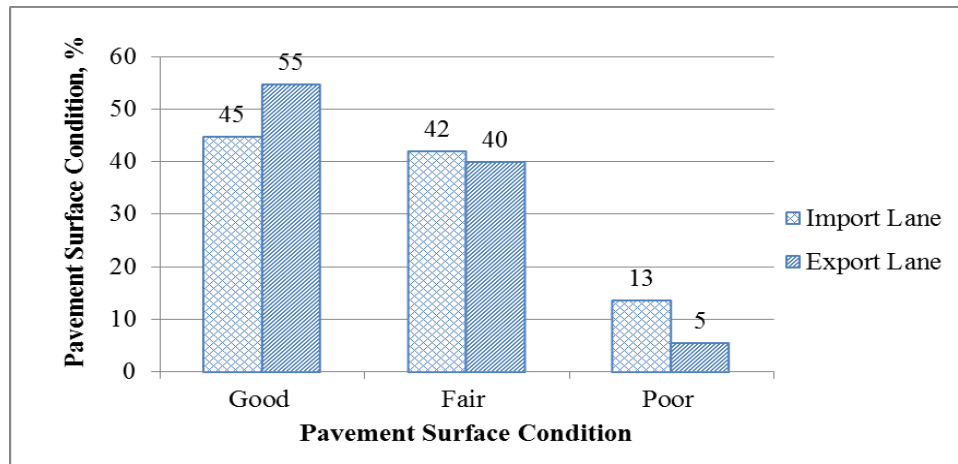


Figure 37. Pavement Surface Condition per Lane

ii. Structural capacity of pavement

The collected deflection data was analyzed and the result shown that the structural condition of the road is sound. The summary of result from deflection calculation on both selected road segment is shown from Table 12 to 15.

Table 12. Structural Condition of Adama - Awash Road Segment, Import Lane

Station from Awash, km	Benkelman Beam Dial Gauge Reading (0.01 mm)	Field Deflection 2x(0.01mm)	Surface Temperature (°C)	Correction for Standard Pavement Temperature (35°C)	Corrected Deflection (µm)	FWD Deflection	Structural Condition (Sound, Warning or Sever)
0.0	15	0.3	25	0	300	186	Sound
3.8	23	0.46		0	460	286	
6.1	10	0.2		0	200	124	
8.4	16	0.32		0	320	199	
10.1	7	0.14		0	140	87	
27.5	11	0.22	32	0	220	137	
28.0	25	0.5		0	500	311	

Table 13. Structural Condition of Adama - Awash Road Segment, Export Lane

Station from Adama, km	Benkelman Beam Dial Gauge Reading (0.01 mm)	Field Deflection 2x(0.01mm)	Surface Temperature (°C)	Correction for Standard Pavement Temperature (35°C)	Corrected Deflection (µm)	FWD Deflection	Structural Condition (Sound, Warning or Sever)
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Station from	Benkelman Beam Dial	Field Deflection	Surface Temperature	Correction for Standard	Corrected Deflection	FWD Deflection	Structural Condition
0.5	6	0.12	25	0	120	75	Sound
3.8	6	0.12			120	75	
6.6	5	0.10			100	62	
8.6	8	0.16			160	99	
10.2	16	0.32			320	199	
27.7	18	0.36	32		360	224	
28.0	18	0.36			360	224	

Table 14. Structural Condition of Awash – Awash Arba Road Segment, Export Lane

Station from Awash, km	Benkelman Beam Dial Gauge Reading (0.01 mm)	Field Deflection 2x(0.01mm)	Surface Temperature (°C)	Correction for Standard Pavement Temperature (35°C)	Corrected Deflection (µm)	FWD Deflection	Structural Condition (Sound, Warning or Sever)
0.0	8	0.16	42	0.07	90	56	Sound
1.0	3	0.06			0	0	
2.0	6	0.12			50	31	
3.0	22	0.44			370	230	
4.0	9	0.18			110	68	
5.0	20	0.4			330	205	
6.0	10	0.2			130	81	
7.0	16	0.32			250	155	

Table 15. Structural Condition of Awash – Awash Arba Road Segment, Import Lane

Station from Awash Arba, km	Benkelman Beam Dial Gauge Reading (0.01 mm)	Field Deflection 2x(0.01mm)	Surface Temperature (°C)	Correction for Standard Pavement Temperature (35°C)	Corrected Deflection (µm)	FWD Deflection	Structural Condition (Sound, Warning or Sever)
0.5	7	0.14	42	0.07	70	43	Sound
1.5	8	0.16			90	56	
2.5	12	0.24			170	106	
3.5	13	0.26			190	118	
4.5	6	0.12			50	31	
5.5	14	0.28			210	130	
6.5	14	0.28			210	130	

Even if, the structural condition of the selected road is sound, the deflection between the two lanes and along the road segment is not uniform as shown in Figure 38.

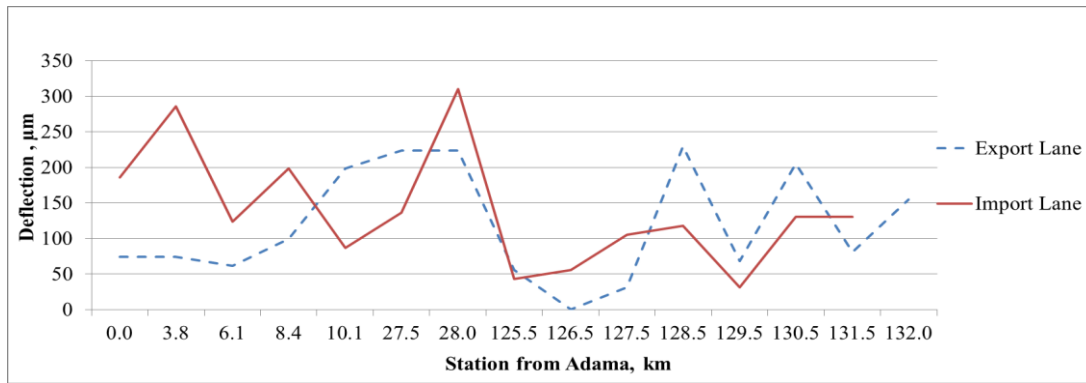


Figure 38. Deflection difference between import and export lanes

iii. Existing pavement failures location

To identify the cause of failures easily, the common and different locations of failures was separated based on the result from surface damage index. The summary of failure location from 144.5 Km damaged section is shown in Figure 39.

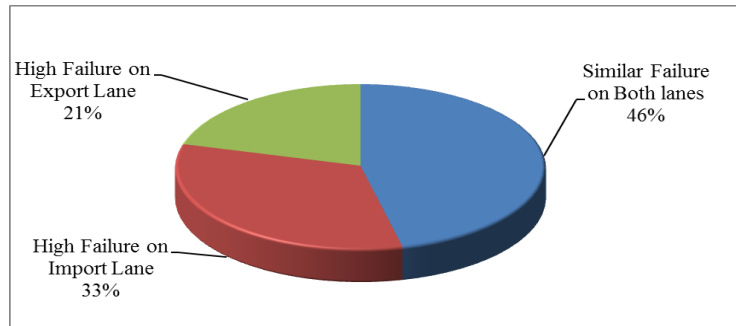


Figure 39. Identified Pavement Failure Location per Lane

iv. Cause of identified pavement failures

The detailed result from analysis of cause of existing pavement failures based on the four cases is attached as annex 4 and the summary of the results are shown below.

Case 1: Sections which have similar failures on both lanes (43.5Km)

The summary of causes of failures related with traffic load under sections which have the same pavement surface condition on both lanes is shown in Figure 40.

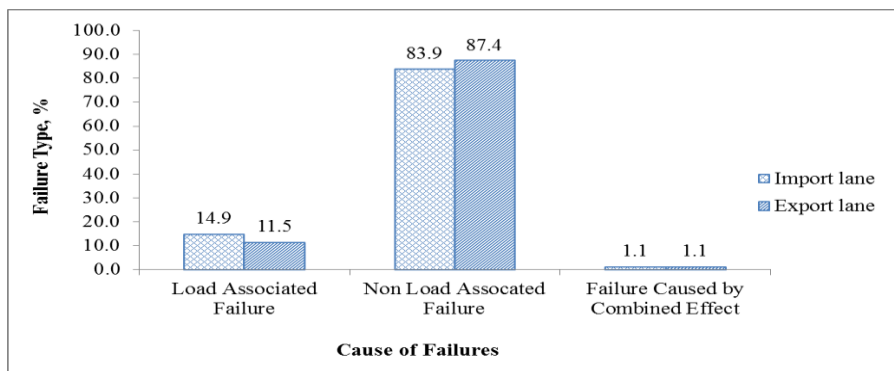


Figure 40. Cause of Identified Failures per Lane, Case I

Case 2: Sections which have high failures on the import lane (34Km)

The summary of causes of failures related with traffic load under sections which have high failures on the import lane is shown in Figure 41.

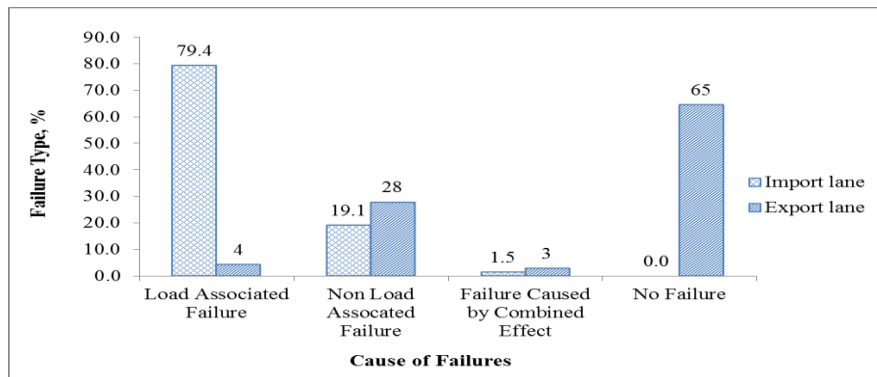


Figure 41. Cause of Identified Failures per Lane, Case II

Case 3: Sections which have high failures on the Export lane (18Km)

The summary of causes of failures related with traffic load under sections which have high failures on the export lane is shown in Figure 42.

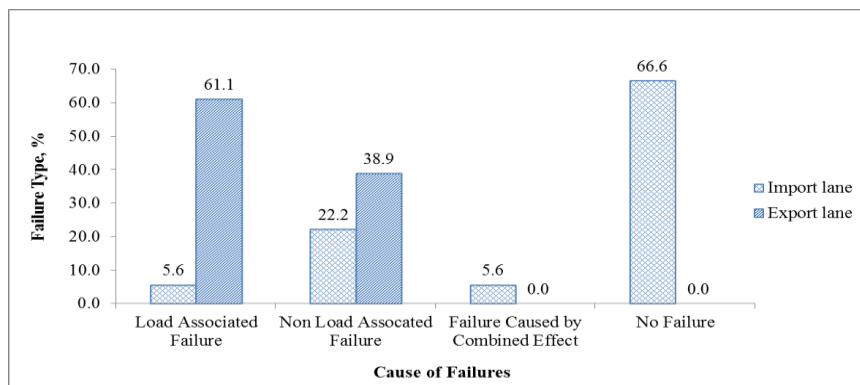


Figure 42. Cause of Identified Failures per Lane, Case III

Case 4: Sections under Good Drainage and Subgrade Area (49.5Km)

The summary of causes of failures related with traffic load under sections which have high failures on the export lane is shown in Figure 43.

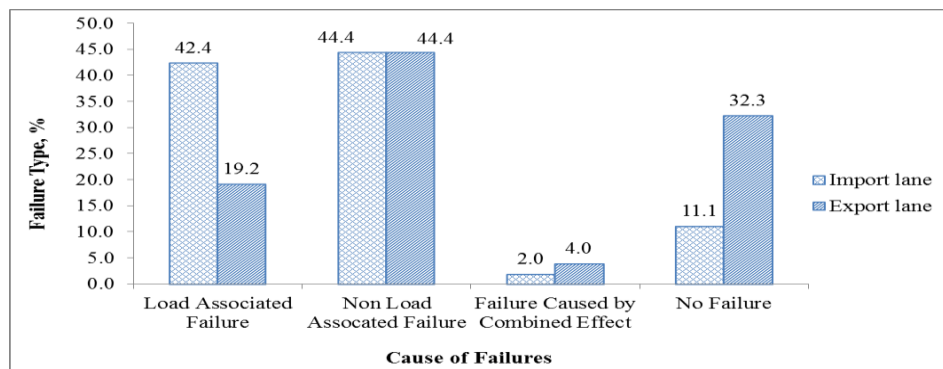


Figure 43. Cause of Identified Failures per Lane, Case IV

Finally, from the above four cases, the cause of existing pavement failure is summarized as shown in Table 16 and Figure 44.

Table 16. Summary of Cause of Existing Failures per Lane and Different Case

	Total Length (Km)	Import Lane				Export Lane			
		Load Associated Failure (%)	Non-Load Associated Failure (%)	Failure Caused by Combined Effect (%)	No Failure (%)	Load Associated Failure (%)	Non-Load Associated Failure (%)	Failure Caused by Combined Effect (%)	No Failure (%)
Case 1	43.5	15	84	1	0	11	87	1	0
Case 2	34	79	19	1	0	4	28	3	65
Case 3	18	6	22	6	67	61	39	0	0
Case 4	49.5	42	44	2	11	19	44	4	32
Total	145	38	48	2	12	19	53	2	26

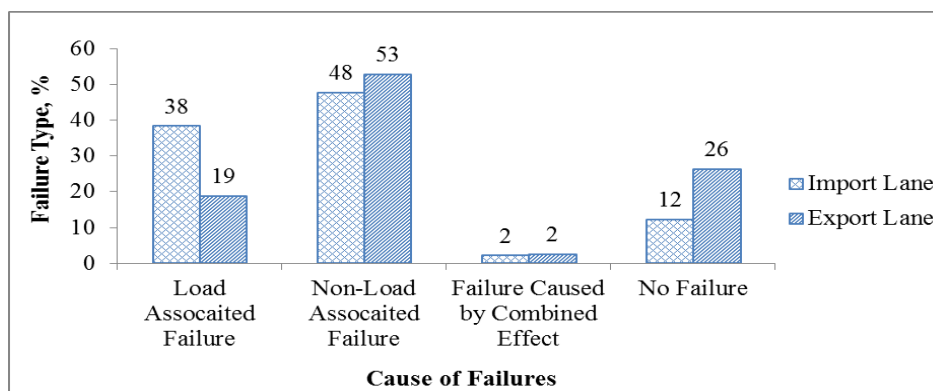


Figure 44. Summary of Cause of Existing Failures per Lane

4.3 Management of load balance

4.3.1. Handling of load balance during design stage of pavement

Questionnaire survey was conducted to identify the way of handling of load balance during design stage of pavement. A total of 35 respondents (Pavement Engineers) from different consulting office with the following general information were participated on the survey.

General Information

- All respondents have a minimum of BSc Degree in Civil Engineering or related fields
- 63% of the respondents have more than 10 years' experience, 29% of the respondents have 5 to 10 years' experience and the remaining 9 % of the respondents have 2 to 5 years' experience in road sector.

i. Accuracy of axle load survey data collected by ERA

49% of the respondents have indicated that the axle load survey data collected by ERA is not accurate and 34% of the respondents were indicated that it is accurate. However, 17% of the respondents were not given response.

ii. Source of axle load survey data for road design projects

40% of the respondents have not used the axle load data collected by ERA since it is not accurate, not separated by lane and does not include all types of vehicles. However, 27% of the respondents have used the data collected by ERA and the remaining 37% of the respondents have used by mixing the data from ERA and collected by their own team.

iii. Selection of Equivalent Factor (EF) to analyze Equivalent Single Axle Load (ESA) per design period

37% of the respondents used equivalent factor from more heavily trafficked lane, 26 % of the respondents used average equivalent factor from the two lanes and 14% of the respondents used equivalent factor calculated from axle load legal limit to analyze Equivalent Single Axle Load (ESA) per design period as shown in Figure 45.

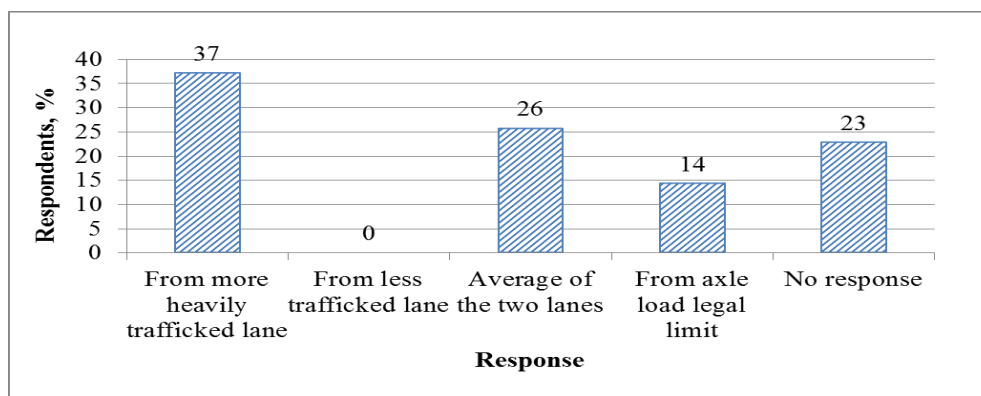


Figure 45. Selection of EF to analyze ESA per design period of the road

iv. Application of different considerations for more heavily trafficked lane along Addis Ababa – Djibouti route or any other routes which have high axle load difference between the two lanes during design stage.

All respondents indicated that any other different consideration is not applied for roads with high load difference between the two lanes.

4.3.2. Handling of load balance during service stage of pavement (Efficiency of vehicle weight and size control station)

i. Load associated failures along the two road segments

Awash - Awash Arba road segment (before the control station)

All stretch of import lane from Awash Arba to Awash is damaged by rutting whereas failure is not occurred on the export lane and the primary cause of rutting is traffic load.

Adama – Awash road segment (after the control station)

Load associated failures from both lanes were identified. Out of the selected fourteen highly damaged stations, all stations on the import lane are damaged by load associated failures which includes; rutting, alligator crack, potholes and patch deterioration. However, load associated failures on the export lane has occurred only on four stations out of the selected fourteen stations and the severity of failures are small when compared with the failures on import lane of the same stations.

The summary of load associated failure per road segment is shown in Figure 46.

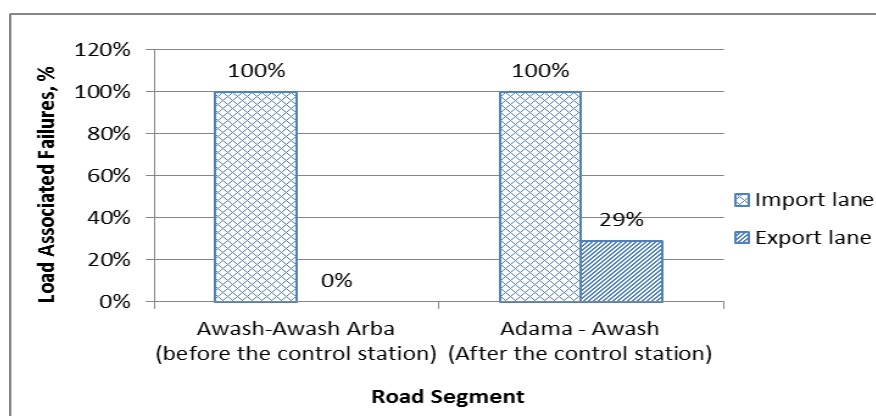


Figure 46. Summary of Load Associated Failure Per Road Segment

ii. Extent of overloading, penalty and corrections for excess load

The overall extent of overloading, penalty and corrections for excess load on the two selected stations was assessed and the following results were found.

Awash vehicle weight and size control stations

Table 17. Weighed Number of Vehicles at Awash Vehicle Weight and Size Control Stations

Date	Weighed Number of Vehicles per Day							Total Number of Weighed Vehicles
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	
July 10-16, 2015	217	201	176	228	268	373	221	1684
October 12-18, 2015	168	127	295	290	279	383	458	2000
November 23-29, 2015	358	346	111*	374	230	120*	364	1903
Total								5587

* weighted small number of vehicles due to power problem

Out of the total 5587 weighed vehicles, 5173 vehicles were beyond the legal limit which is 93% of the total weighed vehicles and 2407 vehicles were beyond 20% overload which is 43% of the total weighed vehicles.

Even if it is not exist on the regulation, the control station permit 20% tolerance for overloaded vehicles and only 154 vehicles were penalized which is 6% of the overloaded vehicles beyond 20%. The summary of overloaded and penalized vehicles on the station is shown in Figure 47.

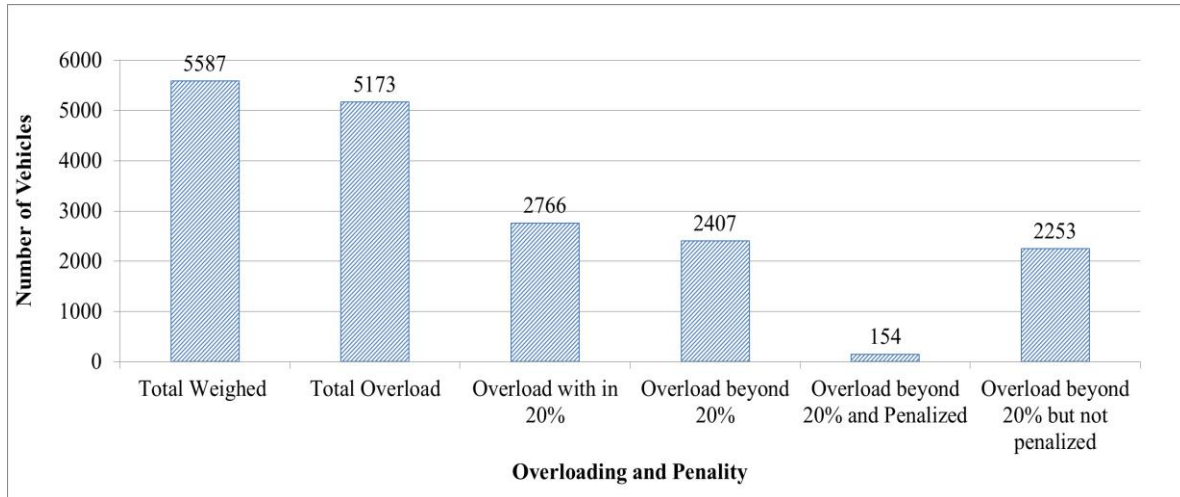


Figure 47. Penalized Number of Vehicles (Awash)

32 vehicles out of the above 154 penalized vehicles have corrected the excess load before traveling further by offloading and rearranging the excess load. However, the remaining 122 vehicles have passed without correcting the excess load which is 79% of the total penalized vehicles. The summary of corrections for excess load on the penalized vehicles is shown in Figure 48.

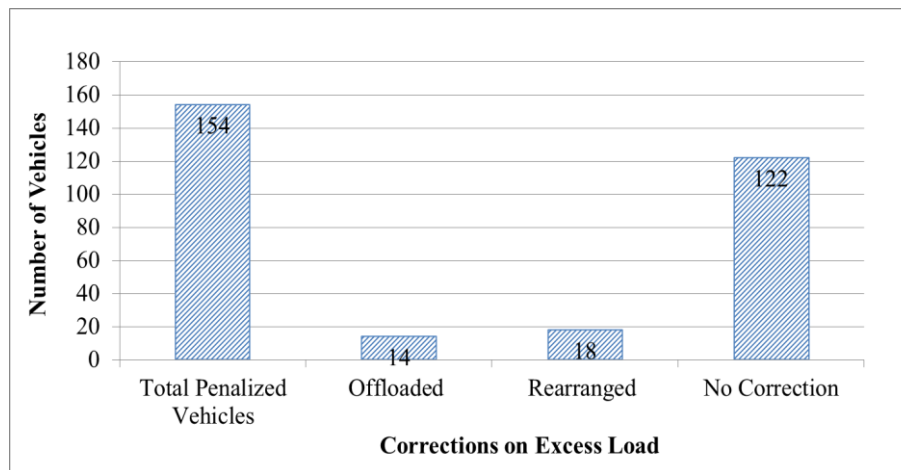


Figure 48. Penalized Number of Vehicles (Awash)

The above penalized 154 Vehicles were paid overload charge. However, the overload charge per tonnes is not uniform, the minimum overload charge per tonnes is 29 ETB and the maximum overload charge is 226 ETB. The overload charge paid by penalized vehicles was varying from the average overload charge which is 76 ETB per tonnes as shown in Figure 49.

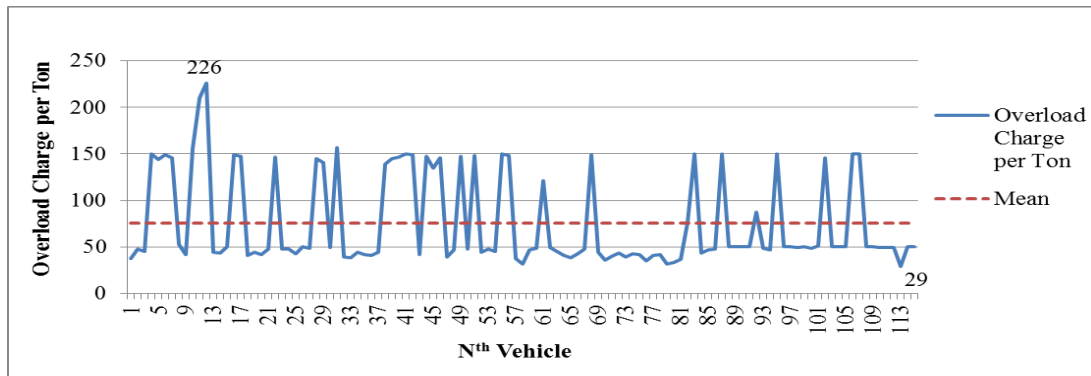


Figure 49. Variance of Overload Charge from Mean (Awash)

Modjo vehicle weight and size control stations

Table 18. Weighed Number of Vehicles at Modjo Vehicle Weight and Size Control Stations

Date	Weighed Number of Vehicles per Day							Total Number of Weighed Vehicles
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	
August 24-30, 2015	368	354	462	369	412	399	76*	2440
September 23-29, 2015	444	323	399	646	201	90*	519	2622
October 20-26, 2015	603	624	552	648	600	286	651	3964
Total								9026

* weighted small number of vehicles on August due the problem of weigh bridge and on September due to holiday.

Out of the total 9026 weighed vehicles, 6032 vehicles were beyond the legal limit which is 67% of the total weighed vehicles and 561 vehicles were beyond 20% overload which is 6% of the total weighed vehicles.

Even if it is not exist on the regulation, the control station permit 20% tolerance for overloaded vehicles and only 116 vehicles were penalized which is 21% of the overloaded vehicles beyond 20%. The summary of overloaded and penalized vehicles on the station is shown in Figure 50.

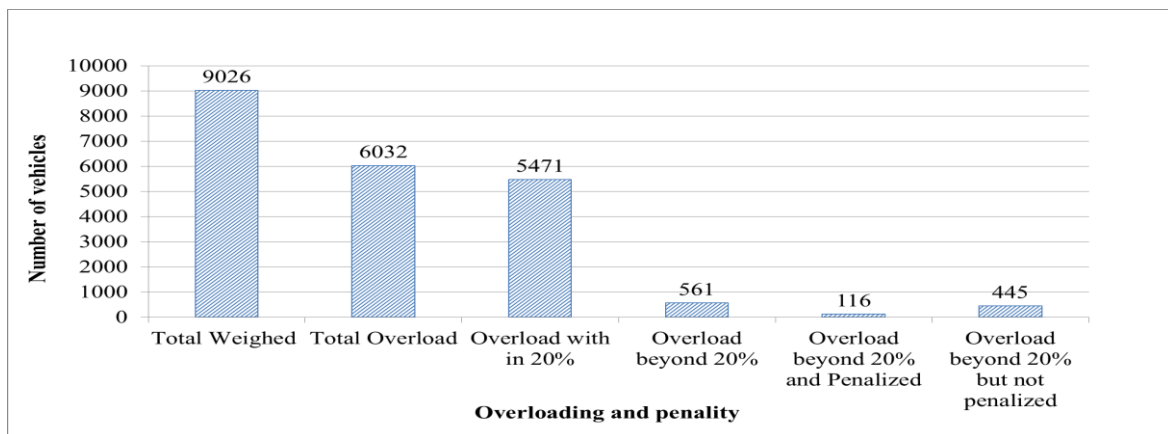


Figure 50. Penalized Number of Vehicles (Modjo)

110 vehicles out of the above 116 penalized vehicles which is 95% have corrected the excess load before traveling further by offloading the excess load. However, the remaining 6 vehicles have passed without correcting the excess load. The summary of corrections for excess load on the penalized vehicles is shown in Figure 51.

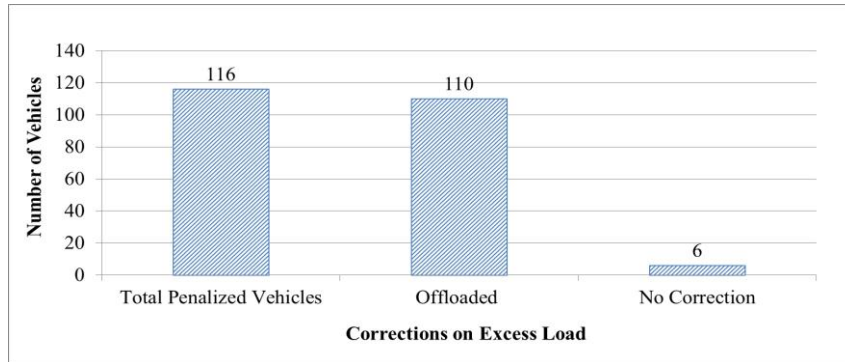


Figure 51. Corrections on Excess Load (Modjo)

The above penalized 116 Vehicles were paid overload charge. However, the overload charge per tonnes is not uniform, the minimum overload charge per tonnes is 39 ETB and the maximum overload charge is 100 ETB. The overload charge paid by penalized vehicles was varying from the average overload charge which is 53 ETB per tonnes as shown in Figure 53.

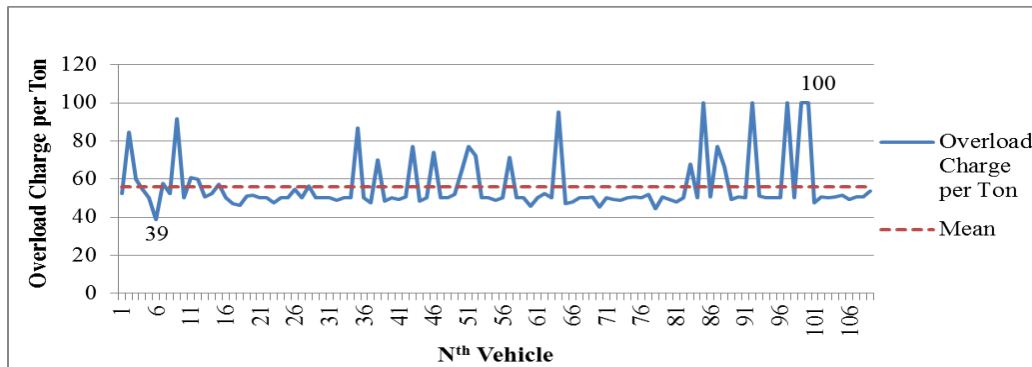


Figure 52. Variance of Overload Charge from Mean (Modjo)

iii. Queue at the control stations

Average waiting time of vehicles in the queue is 6 minutes at both Awash and Modjo vehicle weight and size control stations. The summary of queue analysis result and queue variation per time is shown below.

Table 19. Queue Analysis Result at Awash vehicle weight and size control station

	Number of vehicles in the queue	Arrival Time (Min)	Arrival Rate (λ), Veh/hr	Service Time (Min)	Service Rate (μ), Veh/hr	Waiting time in the queue (Wq), Min
Maximum	19	12	450	19	108	19
Minimum	2	1	68	1	44	1
Average	7	3	184	6	70	6

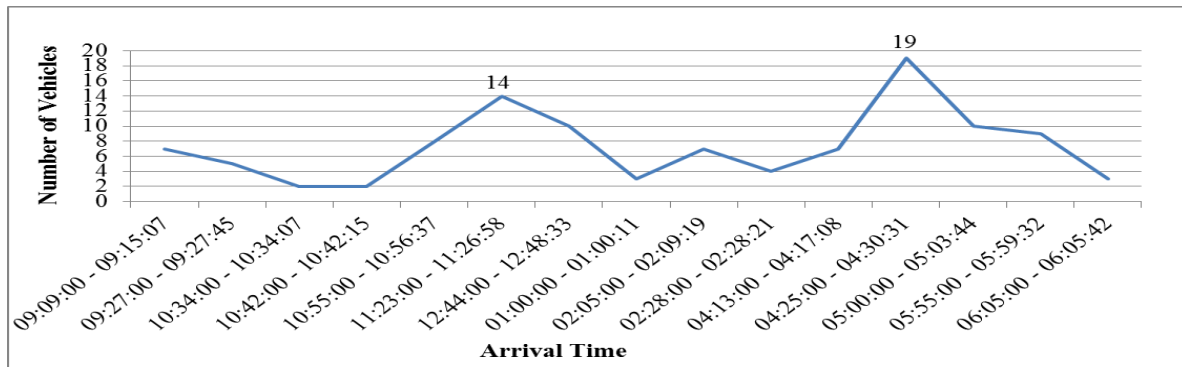


Figure 53. Queue Variation per time at Awash vehicle weight and size control station

Table 20. Queue Analysis Result at Modjo vehicle weight and size control station

	Number of vehicles in the queue	Arrival Time (Min)	Arrival Rate (λ), Veh/hr	Service Time (Min)	Service Rate (μ), Veh/hr	Waiting time in the queue (Wq), Min
Maximum	68	6	982	12	147	36
Minimum	2	0	110	1	56	1
Average	8	2	288	4	92	6

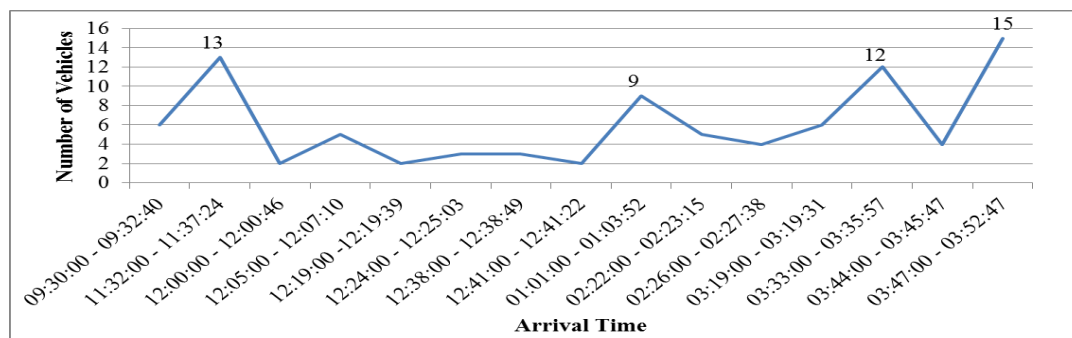


Figure 54. Queue Variation per time at Modjo vehicle weight and size control station

iv. Response on questionnaire survey

Questionnaire survey was conducted to identify the way of handling of load balance during service stage of pavement. The result of the survey from vehicle weight and size control team, control station staffs and drivers is shown below.

Response from vehicle weight and size control team and control station staffs

3 respondents from vehicle weight and size control team, 9 respondents from Awash vehicle weight and size control station staffs and 12 respondents from Modjo vehicle weight and size control station staffs with the following general information have participated on the survey.

General Information

- 50% of the respondents have more than 10 years’ experience, 29% of the respondents have 5 to 10 years’ experience and the remaining 21 % of the respondents have 2 to 5 years’ experience in overload control station.

i. Availability of tolerance for overloaded vehicles

Response from vehicle weight and size control team

All respondents have indicated that there is no any kind of tolerance during controlling of overloaded vehicles.

Response from Awash vehicle weight and size control station staff

78% of the respondents have indicated that they are permit up to 2 tonnes tolerance and 11% of the respondents have indicated that they do not permit any tolerance for overloaded vehicles. However, 11% of the respondents did not respond.

Response from Modjo vehicle weight and size control station staff

All respondents indicated that they permit up to 2 tonnes tolerance for overloaded vehicles.

ii. Weighing system when the static weighbridge malfunctions

Response from vehicle weight and size control team and Awash vehicle weight and size control station staff

All respondents indicated that heavy vehicles are weighed by using mobile weighbridge when the static weighbridge is malfunctions.

Response from Modjo vehicle weight and size control station staffs

58% of the respondents indicated that they do not weigh vehicles when the static weighbridge malfunctions and 33% of the respondents indicated that they used mobile weighbridge. However, 8% of the respondents did not respond.

iii. Permission for overloaded vehicles to travel further without correcting the excess load

Response from Awash vehicle weight and size control station staffs

89% of the respondents indicated that overloaded vehicles can travel further without correcting the excess load and 11% of the respondents indicated that overloaded vehicles are not allowed to travel further without correcting the excess load.

Response from Modjo vehicle weight and size control station staffs

83% of the respondents indicated that overloaded vehicles can travel further without correcting the excess load and 17% of the respondents indicated that overloaded vehicles are not allowed to travel further without correcting the excess load.

Response from vehicle weight and size control team

67% of the respondents indicated that overloaded vehicles can travel further without correcting the excess load and 33% of the respondents indicated that overloaded vehicles are not allowed to travel further without correcting the excess load.

The summary of the response from the three target groups is shown in Figure 55.

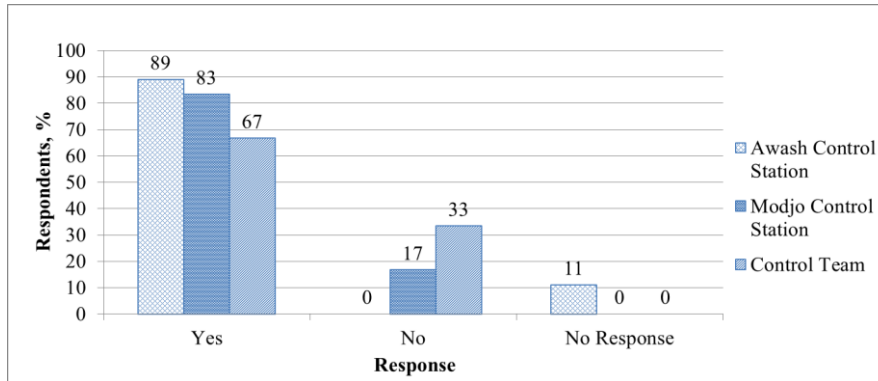


Figure 55. Permission to travel further without correct the excess load

Generally, higher percentage of respondents from both control stations and control team indicated that overloaded vehicles can travel further without correcting the excess load when the overloaded vehicle is its first time, the driver has conditional permission letter from head office of ERA which is given to the driver before the material is loaded at the port, the commodity is sealed, with container or large machinery, for imported materials ordered by government and commodities used to settle the market of the country like oil and wheat. And the respondents also indicated that the conditional permission letter is restricted by size of vehicles, number of axles, routes and bridges that the driver should use.

iv. Existence of vehicles which violate the rule and pass without weighing

All respondents indicated that there are vehicles which violate the rule and pass without weighing.

Response from Drivers

A total of 33 respondents who have experience on Addis Ababa – Djibouti route with the following general information participated on the survey.

General Information

- 55% of the respondents have more than 10 years’ experience, 39% of the respondents have 5 to 10 years’ experience and the remaining 2 % of the respondents have 2 to 5 years’ experience in driving.

i. Awareness on responsibility to protect roads from failures

94% of the respondents indicated that they are responsible to protect roads from failure due to overloading. However, 6% of the respondents indicated that they are not responsible to protect roads from failure.

ii. Awareness on the permission gross vehicle and axle load weight

67% of the respondents know about the difference between gross vehicle and axle load weight. However, 30% of the respondents did not know the difference between gross vehicle and axle load weight and 3% of the respondents did not respond.

iii. Awareness on type of weight which used to control overloading

85% of the respondents have given the correct response which is overloading control is taken by axle load weight. However, 6% of the respondents were incorrect or they considered that overloading is controlled by gross vehicle weight and 9% of the respondents did not respond.

iv. Awareness on Legal axle load limit

Only 9% of the respondents have given the correct response. However, 64% of the respondents have not given response, 12% of the respondents were incorrect, 9% of the respondents were given response by gross vehicle weight and 6% of the respondents were considered the tolerance as legal limit as shown in Figure 56.

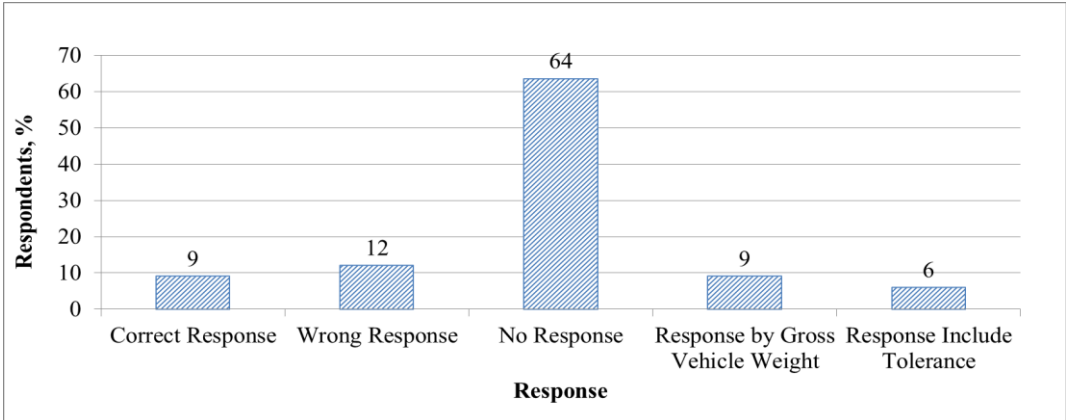


Figure 56. Legal axle load limit

v. Measures taken on overloaded vehicles

Response on Awash vehicle weight and size control station

48% of the respondents indicated that the penalty taken was only overload charge, 3% of the respondents indicated that only offload/rearrangement was made on the excess load

and 12% of the respondents indicated that both overload charge and offload was taken. However, 6% of the respondents indicated that no measures were taken.

Response on Modjo vehicle weight and size control station

39% of the respondents indicated that the penalty taken was only overload charge, 3% of the respondents indicated that only offload/rearrangement was made on the excess load and 15% of the respondents indicated that both overload charge and offload was taken. However, 9% of the respondents indicated that no measures were taken.

The summary of the response from drivers on Awash and Modjo vehicle weight and size control station regarding the measures on overloaded vehicles is shown in Figure 57.

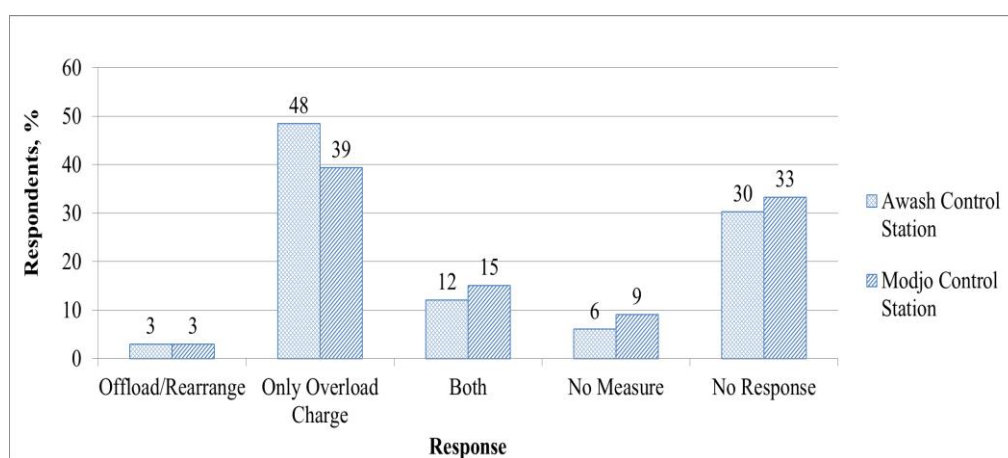


Figure 57. Measures taken on overloaded vehicles

- vi. Transparency of measures taken by control station on overloaded vehicles

Response on Awash vehicle weight and size control station

42% of the respondents indicated that the measures taken by the station on overloaded vehicles are not transparent and does not follow the regulation and 39% of the respondents indicated that the measures are transparent and follows the regulation. However, 18% of the respondents were not given response.

Response on Modjo vehicle weight and size control station

36% of the respondents indicated that the measures taken by the station on overloaded vehicles are not transparent and not depends on the regulation and 45% of the respondents indicated that the measures are not transparent and depends on the regulation. However, 18% of the respondents were not given response.

The summary of the response from drivers is shown in Figure 58.

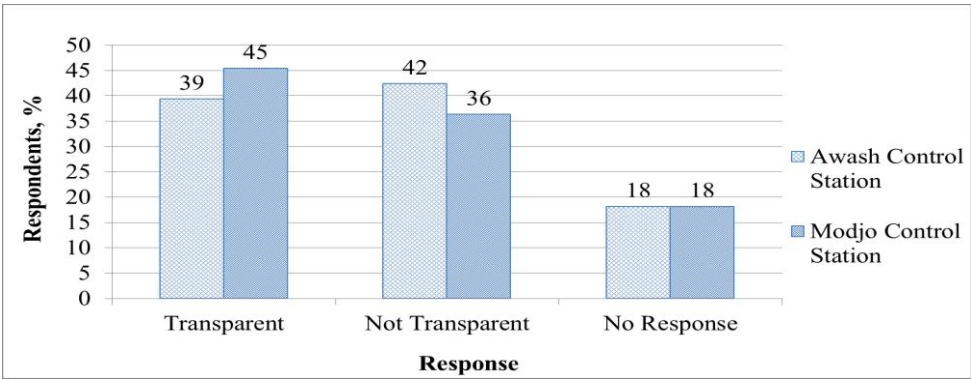


Figure 58. Transparency of measures on overloaded vehicles

5. DISCUSSIONS

5.1 Impact of load imbalance on pavement service life

The comparative assessment of actual pavement service life from the design life (20 years) and between the two lanes shown that, the actual pavement service life of heavily trafficked lane is reduced by 71% (14years) and 38% (8 years) along Awash-Mille and Adama-Awash road segment respectively whereas the actual pavement service life of less trafficked lane is increased by 55% (11 years) and 9% (2 years) along Awash-Mille and Adama-Awash road segment respectively.

The different result of actual pavement service life between the two lanes and road segment was the result of applied traffic load, its repetition and percentage composition of heavy vehicles. From the calculation of ESAs, it was found out that the damage effect of existing heavy vehicles relative to the standard load on import lane is 5.3 and 4.8 times of the export lane along Awash-Mille and Adama-Awash road segment respectively which is the main indicator of existence of imbalance traffic load and its effect between the two lanes. The second indicator of existence of imbalance load between the two lanes is percentage of overloading. As shown from the result of overloading assessment per lane, the percentage of overloading along the import lane is 92% on both road segments whereas it is 15 and 17% along export lane of Awash-Mille and Adama-Awash road segment respectively. The final indicator of existence of imbalance load is the percentage of empty running vehicles; it was found that 84 and 82% of running vehicles on the export lane is empty along Awash-Mille and Adama-Awash road segment respectively. However, almost all vehicles running on the import lane of both road segments is loaded. Hence, the identified reduction and increase of design pavement service life between the two lanes is the result of imbalance load.

It was also found out that even if the damage effect of existing traffic load obtained from the two road segments was similar, the actual service life of the two road segment is different. 66% and 14% of the total vehicles along Awash-Mille road segment is truck and trailers; and heavy trucks, respectively, whereas along Adama-Awash road segment it is only 28% and 16% of the total vehicles, respectively. It indicates that 80% of the total vehicles along Awash-Mille road segment are heavy vehicles whereas it is only 44% along Adama-Awash road segment. Hence, when compared the actual service life of the two segments, the actual service life of import lane along Awah-Mille road segment is low due to the existing high percentage of heavy vehicles and the actual service life of export lane

is high due to the 84% of existing empty running heavy vehicles. Hence, the main cause of actual service life difference between the two road segments is percentage composition of heavy vehicles because actual pavement service life is a function of both vehicle damage factor and percentage composition of vehicles.

As shown from the result especially from Awash-Mille road segment, there is a large difference of actual pavement service life between the two lanes. Hence, different consideration during design, construction or service life stage is essential. However, the road was designed to carry only the legal axle load limit which is below the actual load on heavily trafficked lane and above on less trafficked lane. Hence, the designed pavement for heavily trafficked lane could not be able to resist the actual load. It cause pavement failures and induced unexpected expenditure on pavement investment. According to the data from Ethiopian Roads Authority, the government of Ethiopia has expended ETB 1.5 Billion or ETB 6 Million/Km to rehabilitate the selected road segment before the design period and it may also increase as the road is under construction. Other countries like South Africa, Sweden, Germany and USA used rigid pavement for heavily trafficked lane and flexible pavement for less trafficked lane to design the road economically and to protect unexpected expenditure before the design period of the pavement.

Daniel Legesse, 2013, and Addis Mehari, 2015, computed the impact of overloading on pavement service life even if the load were not separated by lanes. Danel Legesse, 2013 has found out that 11.2% overloading cause 21% pavement service life reduction along Adama-Awash road segment and Addis Mehari, 2015 has found out that 48% overloading cause 45% pavement service life reduction on Awash Junction rigid pavement approach. However, from this study it was found out that 92% overloading on heavily trafficked lane cause 38% pavement service life reduction along Adama-Awash road segment and 71% pavement service life reduction along Awash-Mille road segment. When compared the result of this study with the previous two studies along the same section which is Adama-Awash road segment, the result of pavement service life reduction which is found from this study is relatively small though the percentage of overloading is high. The possible factors which can affect the result of the three studies are the methods used, the time of data collection, the accuracy of collected data and the degree of existing overloading. Both previous studies used axle load data on both lanes together and forecast the existing Equivalent Single Axle Load (ESAL) for the design period to estimate the actual pavement service life. Hence, uses of axle load data on both lanes together increase the impact of

load on pavement because the damage effect of axle load depends on both repetition and degree of overloading; and the calculation of annual growth rate which used to forecast ESAL for estimation of actual pavement service life also affect the result. However, in this study, the collected axle load survey data was separated by lanes and road segment; and the actual pavement service life was also estimated from the actual equivalent standard axles (ESAs). In addition, regarding data collection, Addis Mehari, 2015 used only one day afternoon and one day morning axle load survey data to analyze the pavement service life reduction. However, one day data cannot represent the actual situation because the traffic flow, percentage and degree of overloading is different from day to day and seasons.

According to the information taken from ERA, the rehabilitation of Modjo-Awash-Mille road with Asphalt Concrete surfacing was carried out from 1999 to 2005 and it was opened for traffic in 2003. However, now it is also under overlay construction and the process of procurement to rehabilitate this road segment was started in 2010 it is only after 7 years of last rehabilitation period whereas the design period of the road was 20 years. The time between the two rehabilitation periods is similar with the result of actual pavement service life analysis of heavily trafficked lane along Awash-Mille Road segment of this study which is 6 years.

5.2 Impact of load imbalance on pavement conditions

Even if, traffic load is the main factor which influences the performance of pavement, there are also other factors like temperature change, poor drainage conditions, weak subgrade and construction quality. Hence, to identify the existing failures are load associated or not, the cause of failures was studied. Before identifying the cause of failures, the pavement surface condition and structural capacity of the selected road segment was assessed to know the general condition of road. And it was found out that 55% of the import lane and 45% of the export lane is under fair and poor surface condition. Out of this 13% of the import lane and 5% of the export lane is poor. However, as shown from the result there is no that much high difference between the two lanes pavement surface condition whereas the calculated reduction of pavement service life due to the existing traffic load was very high on the import lane. In addition, 46% of the existing failures are the same between the two lanes, 33% of the existing failures are high on the import lane and 21% of the existing failures are high on export lane.

The result of deflection analysis indicated that the structural capacity of pavement along the selected road segment is sound because the deflection test is taken on the road segment

which is rehabilitated recently and more rutted section which is compacted by traffic. However, the deflection analysis result between the two lanes and along the road segment is not uniform. It indicates that the structural capacity of the road may be affected by subgrade soil type, its moisture content and compaction, the thickness and quality of the pavement courses, drainage conditions and pavement surface temperature.

The above pavement surface condition and deflection analysis results indicated that there are other factors which can affect the performance of the road and reduce the load bearing capacity. Hence, to find the pure impact of imbalance load on pavement conditions, the damaged sections were classified in to four sections which are sections which have the same road condition on both lane, sections which have high failures on the import lane, sections which have high failures on the export lane and sections under good drainage and subgrade area. Then, the causes of existing failures along the classified sections were analyzed separately and the following was found out from the result.

Case I: Sections which have similar failures on both lanes (43.5Km)

In this case, only 14.9% of the failures along the import lane and 11.5% of the failures along the export lane are load associated. However, out of the remaining failures, 83.9 % and 1.1% of failures along the import lane and 87.4 % and 1.1% of failures along the export lane are non-load associated and failures caused by combined effect respectively.

Out of non-load associated failures along the import lane 55% are joint longitudinal crack and long longitudinal cracks across the road; and 29% are fatigue cracks across the road and associated with depression. These types of failures are caused by movement of supporting layers under the surface course due to instability, weak subgrade (expansive soil), poor drainage and lack of cohesion in the surface material. In addition, the failures are occurred on poor road bed (dark clay), poor drainage and swampy area. The existence of moisture and dark clay subgrade reduce the bearing capacity of the pavement since dark clay is expanding when it found moisture and it creates subgrade movement. Hence, even if the traffic load at the import lane is higher than the export lane, the failures occurred on this sections is similar between the two lane which indicated that the road performance is affected by the existing poor drainage combined with dark clay road bed and the pavement structure loose its bearing capacity. Subsequently, the road could not resist even the minimum load on the export lane.

Case II: Sections which have high failures on the import lane (34Km)

In this case, 79.4% of the failures along the import lane are load associated and the remaining 19.1% and 1.5% of the failures are non-load associated and failures caused by combined effect respectively. Along the export lane only 4% of the failures are load associated and out of the remaining 28% and 3% of the failures are non-load associated and failures caused by combined effect respectively. However, 65% of the section along the export lane has no failure.

Out of 79.4% of load associated failures on the import lane, 75% of failures are rutting and fatigue cracks which are the main load associated failures whereas the load associated failures occurred on the export lane was only short longitudinal cracks on the wheel path and pothole. The causes of existing non-load associated failures are moisture with poor subgrade and poor construction as discussed under case I.

Case III: Sections which have high failures on the export lane (18Km)

In this case, 61.1% of the failures along the export lane are load associated and the remaining 38.9% of failure is non-load associated. However, along the import lane only 5.6% of the failures are load associated. Out of the remaining sections along the import lane 22.2%, 5.6% and 66.6% of sections have non-load associated, failures caused by combined effect and no failure section respectively. It was unexpected because the actual load on the import lane is much higher than the export lane and the export lane also designed to carry above the actual load. The causes of existing non-load associated failures on both lanes are moisture with poor subgrade and poor construction. In this failure section, swell is also occurred on the export lane which is the main indicator of expansion of supporting layers under the surface course or the subgrade due to moisture and subgrade with highly plastic clay. In addition, according to the data from Net Consulting Engineers and Architects P.L.C, the ditches on the right side (export lane) require maintenance. Hence, the moisture effect could be high on the export lane and it decreases the bearing capacity of the road. Furthermore, overtaking also has its own effect. Then the export lane cannot able to resist at least the existing small load when compared with the import lane.

Case IV: Sections under good drainage and subgrade area (50Km)

Even if, the considered failure section was filtered from poor drainage and subgrade area, the sections around this area has also affected by the existing moisture but it has given a

better view about the impact of load compared with case I and III. In this case, 42.4% of the failures along the import lane are load associated, 44.4% of the failures are not load associated, 2.0% of the failures are caused by combined effect and the remaining 11.1% of the section has no failure. However, along the export lane 19.2% of the failures along the export lane are load associated, 44.4% of the failures are not load associated, 4.0% of the failures are caused by combined effect and the remaining 32.3% of the section has no failure. As shown from the result, relatively high percentage of load associated failures was occurred on the import lane.

Finally, it was found that even if heavily trafficked lane has highly affected by load compared with the less trafficked lane, the overall selected road segment has affected by poor drainage, poor subgrade, swampy area and construction problem. Hence, to show the pure impact of existing load imbalance on pavement conditions, case II is preferable (see Figure 41).

5.3 Management of load balance

To identify the management of load balance, handling of the load difference between lanes during design stage and service life of pavement was assessed.

5.3.1 Handling of load balance during design stage

According to ERA Pavement Design Manual Volume 1: Flexible Pavement. 2002 & 2013, separate equivalent factor for each direction should be derived and the higher of the two directional values should be used for pavement design. In addition, Special allowance also must be made for unusual axle loads on roads where the vehicles traveling one way are heavily loaded but are empty on the return journey or when it mainly serve one specific economic activity. However, the design manual is not indicate clearly the maximum permitted load or allowance which should considered during design period. Hence, different road projects use different design mechanism. For example, rehabilitation of Adama-Awash-Mille road, 1997, was designed based on equivalent factor from the legal axle load limit, Adama-Awash road overlay. 2012, was designed based on equivalent factor from Adama-Awash road and Addis Ababa-Adama road together to make the design consistent with the adjacent road; and Awash-Mille road overlay. 2012, was designed based on equivalent factor from actual load on highly trafficked lane with power 4.2 whereas as per ERA manual the recommended damage exponent to calculate equivalent factor is 4.5.

To get more and general information about the application of equivalent factor during design stage, survey was conducted using questionnaire and it was found out that 37% of the respondents are used equivalent factor from more heavily trafficked lane, 26 % of the respondents are used average equivalent factor from the two lanes and 14% of the respondents are used equivalent factor calculated from axle load legal limit. Hence, the response from the survey and the methods taken from Engineering design report along the selected road segment indicated that uniform design mechanism is not applied for road design projects. From the survey it is also found out that there is no any different consideration for roads which have high axle load difference between the two lanes during design stage. Therefore, the performance of road can affect by the applied load easily if there is no studied and standard design mechanism which consider the actual condition.

Furthermore, according to ERA Pavement Design Manual Volume 1: Flexible Pavement, 2013, several axle load surveys which includes periods that will reflect seasonal changes are recommended. However, there is no full axle load survey database system in Ethiopia. Hence, each project depends on axle load survey data collected by consultant, data from ERA or mixing of the two data but axle load survey data collected from ERA is not full for design purpose because it is only for heavy loaded vehicles and not separated by direction. As per the result from the survey, 40% of the respondents use their own data, 27% of the respondents use ERA's data and 37% of the respondents used both data to design road projects.

The reliability of axle load survey data collected from ERA is also doubtful since from the survey it was found out that 49% of the respondents were indicated that the axle load survey data collected by ERA is not accurate. The data collected by consultants also does not show seasonal variations. Therefore, the axle load survey data used for design may not represent the actual condition and it affects the standard of road.

5.3.2 Handling of load balance during service life of pavement

To protect the road from failure caused by overloading, ERA has established two static Vehicle Weight and Size Control Stations along the selected road segment. Namely: Awash and Modjo Vehicle Weight and Size Control Stations. However, the station is located 401km away from the port and the safety of remaining road segment also depends on the effectiveness of the existing overload control stations along the route.

During the time of visual condition survey, it was found out that the road section found between the two control stations also affected by load associated failures. However, if the control stations control overloaded vehicles well and if they are not allow them to travel further without offloaded or rearranged the excess load, at least the remaining segment of the road was protected from load associated failures. Hence, the effectiveness of existing overload control stations was assessed based on axle load survey data, measures on overloaded vehicles, queue and questionnaire; and the following was found out;

- **Percentage of Overloading**

- Awash vehicle weight and size control station*

The result from the study shown that, 93% of the total weighed vehicles are above the legal limit and out of this 43% is beyond 20% overload. However, the percentage of overloading reported by ERA on 2014/15 was only 5.2%. Both Awash and Modjo control stations permits 20% tolerance for overloaded vehicles even if it is not exist on the axle load control regulation but the percentage of overloading reported by ERA also much lower than the percentage of overloading found from this study which is beyond 20% overload.

Daniel Legesse, 2013, and Addis Mehari, 2015, found out that 11.2% and 48% of the total weighed vehicles are above the legal limit respectively. When compared the result of this study with the previous two studies, the percentage of overloading found from this study is higher than the two. This is due to the time of data collection, accuracy of data and the method used. Daniel Legesse estimated the overloading based on ERA historical axle load survey data and it was before 3 years. Hence, with in this 3 years the degree of overloading can increase and the time of data collection also affect the degree of overloading. Addis Mehari use only one day axle load survey data which cannot represent the actual condition of traffic flow or which is not include day and seasonal variation of traffic flow. Furthermore, both previous studies used only rear axle load data to estimate the percentage of overloading. However, front axle also overloaded even if the probability of overloading is less.

- Modjo vehicle weight and size control station*

The result from the study shown that, 67% of the total weighed vehicles are above the legal limit and 6% beyond 20% overload. However, the percentage of overloading

reported by ERA on 2014/15 was 8%. Regarding the percentage of overloading beyond 20% overload, the result from the study and ERA is almost similar.

Daniel Legesse, 2013, and Biniyam T. 2015, found out that 4.8% and 45.3% of the total weighed vehicles are above the legal limit respectively. When compared the result of this study with the previous two studies, percentage of overloading found from this study are higher than the two due to the reasons which is discussed under Awash control station.

- **Measures on Overloaded Vehicles**

- Awash vehicle weight and size control station***

The station was not penalized at least the vehicles which are beyond 20% overload strictly. Out of the 43% of vehicles which are beyond 20% overload, only 6% are penalized and the remaining 94% of overloaded vehicles were not penalized due to unknown reason. Furthermore, the overloaded vehicle's driver should require to offload or rearrange the excess load before travel further. However, 79% of the penalized vehicles were traveled further without correct the excess load.

During the survey, high percentage of the respondents (drivers) indicated that the penalty taken was only overload charge and 6% of respondents indicated that they were passed without any penalty. The respondent from control station also indicated that they permit overloaded vehicles to travel further without correcting the excess load when the overloaded vehicle is its first time, the driver has conditional permission letter from ERA Road Network Management Directorate Director which is given to the driver before the material loaded at the port, the commodity is sealed, with container or large machinery which load is not predictable, materials ordered by government and commodities used to settle the market of the country like oil and wheat. However, this should be correct otherwise the establishment of control station to protect road from damage is meaningless.

- Modjo vehicle weight and size control station***

Even if it is better when compared to Awash control station, out of the 6% of vehicles which are beyond 20% overload, only 21% are penalized and the remaining 79% of overloaded vehicles were not penalized due to unknown reason. Furthermore, 5% of the penalized vehicles were traveled further without correct the excess load with the same reason of Awash control station. The percentage of overloaded vehicles which

traveled further without correct the excess load is less at this station when compared with Awash control station since the most loaded material at this station is sand and it is not difficult to offload and rearrange.

During the survey, high percentage of the respondents (drivers) indicated that the penalty taken was only overload charge and 9% of respondents indicated that they were passed without any penalty. High percentage of respondent from the control station also indicated that they are not weighing vehicles when the static weighbridge is malfunction which affect the control process whereas the respondents from Awash control station indicated that they use mobile weighbridge when the static weighbridge is malfunction. However, during the time of data collection, it was noticed that they are not use static weighbridge when the mobile weighbridge is malfunction.

In addition to the above factors, respondents from both control stations indicated that there are vehicles which violate the rule and pass without weighing. Hence, traffic police or watchman at the control station is essential.

- **Overload Charge for Excess Load**

- Awash vehicle weight and size control station***

The penalized vehicles are required to pay the overload charge to the nearest court. However, there is no fixed overload charge per tonnes. The average overload charge from the collected data within the survey period was 76 ETB or 4 USD per tonnes. It is very low when compared with East Africa Community partner states except Burundi. The minimum overload charge from East Africa Community partner states is 250 USD in Uganda. Furthermore, the process of paying overload charge to the court and unavailability of fixed overload charge increase corruption and it takes time since at the time of penalty the court can be closed. Hence, fixed overload charge per tonnes which considers the road damage cost and decriminalized fee overload charge collecting system should develop to save time and reduce corruption.

- Modjo vehicle weight and size control station***

The average overload charge from the collected data within the survey period was 39 ETB or 2 USD per tonnes. It is low even from Awash Control Station. The variation of overload charge between the two control stations is the indicator of unavailability of uniform controlling system between the two stations.

- **Handling of Queuing**

- Awash vehicle weight and size control station*

The result from queue analysis shown that, vehicles should wait up to 19 minutes in the queue to find service. As per the stations internal rule, the time that the station should take for one vehicle to weigh and register the necessary information is 20 minutes though it is not indicated on the regulation. When compare the result from the study with the limited time, the performance of the station is good even at the busiest time. However, 20 minutes for one vehicle is high. Hence, the time used by the stations should reduce to minimize the impact of queue on pavement.

Moreover, there is Custom office approximately at 1.5 Km from the station and sometimes the queue forming at the custom office extended up to the station which affects the station work. As per the information from the station staff, vehicles can stop at the station from 1 to 6 hours due to the formation of queue at custom office. Hence, slower speeds and stop of vehicles at this time increase the applied load on the pavement and damage. Subsequently, the heavily trafficked lane of the road segment near to the station is affected by high rut compared to the other section of the road segment.

- Modjo vehicle weight and size control station*

It was found out that vehicles should wait up to 36 minutes in the queue to find service during the busiest time. However, at this station the pavement is not affected by the queue because the queue forming area is out of the main road. Hence, attention should be given to the selection of location for vehicle weight and size control station in addition to service time of station to minimize the effect on pavement near to the station.

- **Awareness of Drivers on Overloading Control System**

- ✓ 30% of the respondents did not know the difference between gross vehicle and axle load weight and 3% of the respondents were not given response.
 - ✓ 6% of the respondents were considered that overloading is controlled by gross vehicle weight whereas it is by axle load weight and 9% of the respondents were not given response.
 - ✓ Only 9% of the respondents were given correct response about the legal axle load limit. However, 64% of the respondents were not given response, 12% of

the respondents were incorrect, 9% of the respondents were given response by gross vehicle weight and 6% of the respondents were considered the tolerance as legal limit.

- ✓ 94% of the respondents were indicated that they are responsible to protect roads from failure due to overloading and the remaining 6% of the respondents are indicated that they are not responsible.

Hence, Awareness should be created on the effect of overloading, uses of vehicle weight and size control stations and the control system followed by the station to create responsible drivers.

- **Transparency of measures taken by the control stations on overloaded vehicles**

Almost half of the respondents (drivers) indicated that the measures taken by both vehicle weight and size control stations on overloaded vehicles are not transparent and not depends on the regulation. It is the indication of inefficient of control system and existence of corruption even if the response is unexpected when compared with the data collected from the site. This is may be due to the afraid of respondents to give exact response.

6. CONCLUSIONS

From the assessment of management of load balance and its impact on pavement conditions, the following conclusions were taken.

- The service life of heavily trafficked lane is reduced by 71 % or by 14 years and the service life of less trafficked lane increased by 55% or by 11 years due to the existing load difference between the two lanes.
- The existing load also caused 79.4% load associated failures on heavily trafficked lane and 4% load associated failures on less trafficked lane which includes the effect of overtaking.
- Any kind of different consideration is not applied to handle the load difference between the two directions except consider the legal axle load limit for design purpose and control the overload.
- Each road project depends on axle load survey data collected by the consultant, data from ERA or mixing of the two data. However, axle load survey data collected from ERA is not full for design purpose because it is only for heavy loaded vehicles and not separated by direction. In addition the data collected by consultants is not show seasonal variations.
- Due to unavailability of vehicle weight and size control station at the loading place, vehicles were weighed after damaged high length of road. From the total length of Addis Ababa to Djibouti road which is 627 Km, 401 km length of the road is not protected from overloading since the first vehicle weight and size control station is located at 401Km from Djibouti.
- The percentage of overloading reported by ERA does not indicate the actual condition. Out of the total weighed vehicles at Awash vehicle weight and size control station, 93% are above the legal limit and 43% of the total weighted vehicles are beyond 20% overload whereas the percentage of overloading reported by ERA on 2014/15 was only 5.2% and also at Modjo vehicle weight and size control station, out of the total weighed vehicles, 67% are above the legal limit and 6% of the total weighed vehicles are beyond 20% overload whereas the percentage of overloading reported by ERA on 2014/15 was only 8%.

- The penalty rate on overloaded vehicles is very small on both vehicle weight and size control stations even on the overloaded vehicles beyond 20%. Out of the 43% of vehicles which are beyond 20% overload at Awash vehicle weight and size control station, only 6% are penalized and the remaining 94% of overloaded vehicles were not penalized due to unknown reason. And also at Modjo vehicle weight and size control station, out of the 6% of vehicles which are beyond 20% overload, only 21% are penalized and the remaining 79% of overloaded vehicles were not penalized due to unknown reason.
- 79% of penalized vehicles at Awash vehicle weight and size control station and 5% of penalized vehicles at Modjo vehicle weight and size control station were traveled further without correct the excess load.
- Fixed overload charge per tonnes is not available in the regulation and the overload charge collecting system is criminalized fines. It increase corruption and it takes time since at the time of penalty the court can be closed. The average overload charge collected within the survey period is 76 ETB or 4 USD per tonnes at Awash vehicle weight and size control station and 39 ETB or 2 USD per tonnes at Modjo vehicle weight and size control station. It is not uniform between the two vehicle weight and size control stations and very low when compared with East Africa Community partner states.
- The road section near to vehicle weight and size control station is affected by slower speeds and stop of vehicles at the time of queue if the queue forming area is not out of the main road and due to other factors around the control station which can affect the queue formation at the control station like custom office.
- High percentage of respondents out of the surveyed drivers, have not enough awareness on the control system followed by the vehicle weight and size control Station.
- Almost half of the respondents (drivers) indicated that the measures taken by both vehicle weight and size control stations on overloaded vehicles are not transparent and not depends on the regulation. Hence, it is the indication of inefficient of control system and existence of corruption.

7. RECOMMENDATIONS

The following recommendations are proposed to minimize the constraints causing pavement failures base on the result from the study.

- For new road projects;
 - Option 1: use combined pavement, rigid pavement for heavily trafficked lane and flexible pavement for less trafficked lane.
 - Option 2: design the two lanes separately by using actual load and separate the lane by median or curbs to reduce unnecessary cost which spends on less trafficked lane and also to reduce unexpected expenditure on the pavement investment due to the load which is not considered on the design period.
- For existing road;
 - Option 1: design the pavement with actual load on heavily trafficked lane during rehabilitation of the existing road.
 - Option 2: design the pavement with legal axle load limit and establish strict overloading control system at the initial place of loading and additional important places.
- ERA could prepare regular, updated and reliable directional axle load survey data which includes periods that will reflect seasonal changes, all vehicle types and empty vehicles for design purpose.
- Establish effective, strict, uniform and adequate vehicle weight and size control stations and the control stations could be placed at the initial places of loading to protect the overall road length from damage. Furthermore, during selection of location for vehicle weight and size control station, attention should be given for queue forming area to reduce the effect on pavement around the station and it is preferable if the queue forming area is out of the road.
- The effect of overloading, which caused by allowing overloaded vehicles to travel further without correcting the excess load should be considered during design period if the permissions given by ERA is a must.
- Develop high and fixed overload charge per tonnes which consider the road damage cost and follow decriminalized fee overload charge collecting system to save time,

reduce corruption and use the overload charge for maintenance purpose. Currently, new enforcement procedure is preparing by ERA. Hence, it may reduce the problem.

- ERA could employ traffic police or watchman to control the vehicles which violate the rule and pass without weighing.
- Awareness could be created on the effect of overloading, uses of vehicle weight and size control stations and the control system followed by the station to create responsible stakeholders.

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Annex-1

Axle Load Survey Data Collection Form

Annex-2

Cause of existing pavement failures

Case 1: Sections which have similar failures on both lanes (43.5Km)

Identified Failures and its Causes on Import Lane, Case I

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Longitudinal Crack (Joint)	Poor construction and it may associate with subgrade movement (instability) due to weak subgrade (expansive soil) and poor drainage	16.5	38
Longitudinal crack (short and irregular) on the Wheel path and associated with rut.	Since the distress is short, parallel and along the wheel path, the main cause of failure is traffic load and by further traffic these cracks will interconnect to form alligator crack.	5.5	13
Longitudinal crack , Long, associated with depression and across the road(long longitudinal crack)	Since the crack is long, under poor road bed , swamp area, and associated with depression, the main possible cause is movement of supporting layers under the surface course due to instability and lack of cohesion in the surface material	7.5	17
Total for Longitudinal Crack			68
Fatigue Crack on the wheel path and associated with rut	Since it has occurred on the wheel path and associated with rut the main possible cause is increase in loading (more or heavier loads than anticipated in design)	1	2
Fatigue Crack Across the road and associated with depression	Since the crack occurred across the road and associated with depression, the main cause of the failure is decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade).	12.5	29
Total for Fatigue Crack			31
Patch deterioration associated with rut	Inadequate cleaning or inadequate tack cot before placement of upper layers, seepage of water or moisture, weak or loose layer and traffic load.	0.5	1
Total			100

Identified Failures and its Causes on Export Lane, Case I

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Longitudinal Crack (Joint)	Poor construction and it may associate with subgrade movement (instability) due to weak subgrade (expansive soil) and poor drainage	16.5	38
Longitudinal crack (short and irregular) on the Wheel path and associated with rut.	Since the distress is short, parallel and along the wheel path, the main cause of failure is traffic load and by further traffic these cracks will interconnect to form alligator crack.	4	9
Longitudinal crack , Long, associated with depression and across the road(long longitudinal crack)	Since the crack is long, under poor road bed , swamp area, and associated with depression, the main possible cause is movement of supporting layers under the surface course due to instability and lack of cohesion in the surface material	9	21
Total for Longitudinal Crack			68
Fatigue Crack on the wheel path and associated with rut	Since it is occurred on the wheel path and associated with rut, the main possible cause is increase in loading (more or heavier loads than anticipated in design)	1	2

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Fatigue Crack Across the road and associated with depression	Since the failure is occurred across the road and associated with depression, the main cause of the failure is decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade).	12.5	29
Total for Fatigue Crack			31
Patch deterioration associated with rut	Inadequate cleaning or inadequate tack coat before placement of upper layers, seepage of water or moisture, weak or loose layer and traffic load.	0.5	1
Total			100

Case 2: Sections which have high failures on the import lane (34Km)

Identified Failures and its Causes on Import Lane, Case II

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Rutting with Shoving	Since only the imported lane is affected by rutting, the possible cause of this failure is inappropriate surfacing material for temperature and/or loading regime	9.5	28
Rutting without Shoving	Since only the import lane is affected by rutting and there is significant difference in traffic loading between the two lanes, initial deterioration is the result of excessive traffic loading and /or inadequate pavement layer thickness to resist actual load	8.5	25
Total for rutting			53
Longitudinal crack, short and on the wheel path associated with rut.	Traffic load and by further traffic these cracks will interconnect to form alligator crack	1.5	4
Longitudinal crack, long, out of wheel path and associated with depression	Movement of supporting layers under the surface course due to instability	5	15
Total for longitudinal crack			19
Fatigue Crack on the wheel path and associated with rut	Increase in loading (more or heavier loads than anticipated in design)	7.5	22
Fatigue Crack Across the road and associated with depression	Decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade).	1	3
Total for Fatigue Crack			25
Raveling	Insufficient adhesion between the asphalt cement and aggregate and accelerated by traffic	0.5	1
Patch deterioration with pothole, depressions and long cracks	Inadequate cleaning or inadequate tack coat before placement of upper layers, seepage of water or moisture, weak or loose layer, movement of the supporting layers under the surface course due to instability and traffic load.	0.5	1
Total			100

Identified Failures and its Causes on Export Lane, Case II

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
No Failure		22	65
Longitudinal crack, short and on the wheel path	Traffic load	1.5	4
Longitudinal crack, long or out of wheel path	Subgrade movement	4	12
Longitudinal Crack (Joint)	Poor construction and it may associate with subgrade movement (instability) due to weak subgrade (expansive soil) and poor drainage	4	12
Total for longitudinal crack			28
Fatigue crack across the road	Decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade).	1	3
Raveling	Insufficient adhesion between the asphalt cement and aggregate; and accelerated by traffic	0.5	1
Pothole	Pavement disintegration under traffic loading, moisture or poor drainage and inadequate strength in one or more layers of the pavement.	0.5	1
Patch deterioration with pothole, depressions and long cracks	Inadequate cleaning or inadequate tack coat before placement of upper layers, seepage of water or moisture, weak or loose layer, movement of the supporting layers under the surface course due to instability and traffic load.	0.5	1
Total			100

Case 3: Sections which have high failures on the Export lane (18Km)

Identified Failures and its Causes on Import Lane, Case III

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Fatigue crack at the wheel path	Increase in loading (more or heavier loads than anticipated in design)	1	6
Fatigue crack across the width of the road	Decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade)	1	6
Total for fatigue failure			12
Longitudinal Crack, long, out of wheel path and across the road	Subgrade movement	1.5	8
Longitudinal Crack (Joint)	Joint failure due to poor construction	1.5	8
Total for longitudinal crack			16
Raveling associated with Rutting and pothole	Insufficient adhesion between asphalt cement and aggregate, moisture or poor drainage, inadequate strength in one or more layers of the pavement and traffic load.	1	6
No damage		12	67
Total			100

Identified Failures and its Causes on Export Lane, Case III

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Fatigue Crack associated with rut	Increase in loading (more or heavier loads than anticipated in design)	7	39
Fatigue Crack associated with depression	Decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade).	0.5	3
Total for Fatigue Crack			42
Longitudinal crack, short and on the wheel path associated with rut.	Traffic load and by further trafficking these cracks will interconnect to form alligator crack.	4	22
Longitudinal crack, long, out of wheel path or associated with depression and swell	Movement of supporting layers under the surface course due to instability due to drainage and subgrade problem	4	22
Longitudinal crack (Joint)	Joint failure due to poor construction and it may associate with subgrade movement (instability) due to weak subgrade (expansive soil) and poor drainage	1.5	8
Total for Longitudinal Crack			53
Raveling associated with depression	Insufficient adhesion between asphalt cement and aggregate and localized consolidation or movement of the supporting layers under the surface course due to instability	0.5	3
Raveling	Insufficient adhesion between the asphalt cement and aggregate and accelerated by traffic	0.5	3
Total			100

Case 4: Sections under Good Drainage and Subgrade Area (49.5Km)

Identified Failures and its Causes on Import Lane, Case IV

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
No Distress		5.5	11
Rutting with Shoving	Inappropriate surfacing material for temperature and/or loading regime	8.5	17
Rutting without Shoving	Excessive traffic loading and /or inadequate pavement layer thickness to resist actual load	2.5	5
Total for rutting			22
Fatigue Crack associated with rut	Increase in loading (more or heavier loads than anticipated in design)	8	16
Fatigue Crack associated with depression	Decrease in pavement load supporting characteristics due to poor drainage (loss of base, sub base or subgrade).	6.5	13
Total for Fatigue Crack			29
Longitudinal crack, short and on the wheel path associated with rut.	Traffic load and by further traffic these cracks will interconnect to form alligator crack.	2	4
Longitudinal crack, long, out of wheel path or associated with depression and swell	Movement of supporting layers under the surface course due to instability due to drainage and subgrade problem	7	14

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
Longitudinal crack (Joint)	Poor construction and it may associate with subgrade movement (instability) due to weak subgrade (expansive soil) and poor drainage	8	16
Total for Longitudinal Crack			34
Patch deterioration associated with pothole, depressions and long cracks	Inadequate cleaning or inadequate tack cot before placement of upper layers, seepage of water or moisture, weak or loose layer, movement of the supporting layers under the surface course due to instability and traffic load.	0.5	1
Patch deterioration associated with rut	Inadequate cleaning or inadequate tack cot before placement of upper layers, seepage of water or moisture, weak or loose layer and traffic load.	0.5	1
Raveling	Insufficient adhesion between the asphalt cement and aggregate and accelerated by traffic	0.5	1
Total			100

Identified Failures and its Causes on Export Lane, Case IV

Failure type	Probable Cause of Failure	Length (Km)	Extent (%)
No Distress		16	32
Fatigue Crack associated with rut	Increase in loading (more or heavier loads than anticipated in design)	4	8
Fatigue Crack associated with depression	Decrease in pavement load supporting characteristics due to poor drainage (loss of base, subbase or subgrade).	6	12
Total for Fatigue Crack			20
Longitudinal crack, short and on the wheel path associated with rut.	Traffic load and by further traffic these cracks will interconnect to form alligator crack.	5.5	11
Longitudinal crack, long, out of wheel path or associated with depression and swell	Movement of supporting layers under the surface course due to instability sine there is drainage and soil type problem	5.5	11
Longitudinal crack (Joint)	Poor construction and it may associate with subgrade movement (instability) due to weak subgrade (expansive soil) and poor drainage	10.5	21
Total for Longitudinal Crack			43
Patch deterioration associated with pothole, depressions and long cracks	Inadequate cleaning or inadequate tack cot before placement of upper layers, seepage of water or moisture, weak or loose layer, movement of the supporting layers under the surface course due to instability and traffic load.	0.5	1
Patch deterioration associated with rut	Inadequate cleaning or inadequate tack cot before placement of upper layers, seepage of water or moisture, weak or loose layer and traffic load.	0.5	1
Raveling	Insufficient adhesion between the asphalt cement and aggregate and accelerated by traffic	0.5	1
Pothole	Pavement disintegration under traffic loading, moisture or poor drainage and inadequate strength in one or more layers of the pavement.	0.5	1
Total			100

Annex-3

Overload Charge and Corrections on Excess Load

Overload Charge and Corrections on Excess Load at Awash Vehicle Weight and Size Control Stations

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
July 10-16, 2015	1	TRKTRL	1.22+2.22	12.4	-	11.8	11.8	10.6	8.3	8.3			8.6	not paid at the time of data collection	Container	No Correction
	2	TRKTRL	1.22+ 2.22	7.9	-	14.5	14	10.5	11	10.8			10.8	400	Stone Charcoal	No Correction
	3	SMTRL	1.22 - 22	6.6	-	14	13.9	6.8	6.7				7.9	300	Container	No Correction
	4	SMTRL	1.2 - 2.2	6.9	-	17	12	11.5					10.5	500	Container	No Correction
	5	SMTRL	1.22 - 222	5.8	-	11.6	11.5	14.7	12.7	14			14.5	650	Container	No Correction
	6	TRKTRL	1.22 + 2.22	7	-	14.5	14.2	10.5	11	10.5			10.7	1600	Stone Charcoal	No Correction
	7	TRKTRL	1.22 + 2.22	7	-	14.2	14.2	10.4	11	10.6			10.4	1500	Stone Charcoal	No Correction
	8	TRKTRL	1.22 + 2.22	7.4	-	13.3	12.5	10.2	11.2	11.2			8.4	1250	Sheet Metal	No Correction
	9	TRK	1.2	7.9	-	15.5							5.5	800	Wheat	Offloaded
	10	TRKTRL	1.22 + 2.22	6.8	-	13.8	13.1	8.8	12.1	12			11	not paid at the time of data collection	Sheet Metal	No Correction
	11	TRKTRL	1.22 + 2.22	7.6	-	14.7	14.6	10.7	10.8	10.5			11.3	600	Stone Charcoal	No Correction
	12	SMTRL	1.2 - 22	5.5	-	13	12.5	14					9.5	400	Container	No Correction
	13	TRKTRL	1.22 + 2.22	6.4	-	13	12.5	9	12	11.5			9	1400	Sheet Metal	No Correction
	14	TRKTRL	1.22 + 2.22	7.6	-	12	12	9.4	11	11.9			6.9	1450	Sheet Metal	No Correction
	15	TRKTRL	1.22 + 2.22	7.4	-	12.4	12	9.9	12.5	11.5			8.4	1900	Sheet Metal	No Correction
	16	TRKTRL	1.22 + 2.22	7.1	-	13.6	12.5	12	11	10.3			9.4	420	Sheet Metal	No Correction
	17	TRKTRL	1.22 + 2.22	6.3	-	14	13.5	9.9	12.5	11.5			11.5	500	Plywood	Offloaded
	18	SMTRL	1.22 - 222	6.3	-	13	12.5	14	10	12.5			12	600	Container	No Correction
	19	SMTRL	1.2 - 2.2	6.5	-	15.2	15	13.2					13.4	2000	Container	No Correction
	20	TRKTRL	1.22 + 2.22	7.6	-	14.1	14.2	10.6	11.2	10.1			10.2	1500	Stone Charcoal	No Correction
	21	TRKTRL	1.22 + 2.22	6.8	-	14.7	13.5	9.9	11	10.5			9.7	400	Container	No Correction
	22	SMTRL	1.22 - 222	6.5	-	11.4	12	15	12.5	15			15.9	700	Container	No Correction
	23	TRKTRL	1.22 + 2.22	6.8	-	14	14	10.5	8.4	11			9.5	400	Container	No Correction
	24	SMTRL	1.2 - 22	5.6	-	16.1	10.6	11.7					8.4	400	Container	No Correction
	25	TRKTRL	1.22 + 2.22	6.4	-	15	14.8	10.2	11.6	9.9			11.6	1700	Container	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	26	TRKTRL	1.22 + 2.22	6.9	-	14.5	14.2	10.1	11	10.4			10.2	not paid at the time of data collection	Rice	Offloaded
	27	TRKTRL	1.22 + 2.22	7.2	-	14	13.4	13	9.8	9.6			10.4	500	Coil Sheet Metal	No Correction
	28	TRKTRL	1.22 + 2.22	7.2	-	15	14	10.4	11	9.8			10.4	500	Sesame	No Correction
	29	SMTRL	1.22 - 2.22	7.2	-	13.8	12.8	10.6	10.4	11.8			9.4	400	Container	No Correction
	30	SMTRL	1.22 - 2.22	6.2	-	11	11.5	13	12	14			12	600	Container	No Correction
	31	TRKTRL	1.22 + 2.22	5.1	-	14	13.1	9.4	13.4	11.8			12.3	600	Sheet Metal	No Correction
	32	TRKTRL	1.22 + 2.22	5.7	-	13	13.2	8.1	9.1	7.8			6.2	900	Different materials	No Correction
	33	TRKTRL	1.22 + 1.22	5.1	-	13.6	13.5	9	8.6	8.7			7.1	1000	Sheet Metal	No Correction
	34	TRKTRL	1.22 + 2.22	7.4	-	13.8	13.4	10.4	9.2	11.5			9.1	450	Stone Charcoal	No Correction
	35	TRKTRL	1.22 + 2.22	8	-	14.2	14.3	11.4	11.8	11.7			13.4	not paid at the time of data collection	Sugar	No Correction
	36	SMTRL	1.22 - 2.22	6.5	-	13.4	13	10.4	10.6	14			11.4	not paid at the time of data collection	Sheet Metal	No Correction
	37	TRKTRL	1.22 + 2.22	6.1	-	14.8	14	8.4	11	10.8			10.6	not paid at the time of data collection	Sheet Metal	No Correction
	38	SMTRL	1.22 - 2.22	6	-	12.2	12.6	14	13.2	12.6			14.6	2290	Transformer	No Correction
	39	SMTRL	1.2 - 2.2	6.2	-	17.6	8.5	8.2					7.6	300	Container	No Correction
	40	SMTRL	1.22 - 2.22	7.8	-	12	12	12.3	12.8	13.8			12.9	not paid at the time of data collection	Container	No Correction
October 12-18, 2015	41	TRK	1.22	8.4		16.8	16.3						13.1	500	Salt	Offloaded
	42	SMTRL	1.22-2.22	7.4		10.9	10.2	11.2	11.3	14.5			8.1	not paid at the time of data collection	Sheet Metal	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	43	TRKTRL	1.22+2.22	7.3		11.4	10.8	11.2	10.4	14.6			8.4	not paid at the time of data collection	Container	No Correction
	44	TRKTRL	1.22+2.22	7		11.5	11.5	13.7	12.2	17			15.9	700	Machinery	No Correction
	45	TRKTRL	1.22+2.22	7.2		16.5	16.5	13.4	10.3	9.3			16.7	700	Container	No Correction
	46	TRKTRL	1.22+2.22	7.7		16	15.6	13	11	11.5			17.1	700	Container	No Correction
	47	TRKTRL	1.22+2.22	8.1		16.5	16.1	14	11.4	9			18	800	Container	No Correction
	48	TRKTRL	1.22+2.22	7.1		17.3	16.3	13.6	10.4	10.8			18.2	not paid at the time of data collection	Container	No Correction
	49	TRKTRL	1.22+2.22	5.8		14.4	13.5	9.5	9.1	9.1			7.9	1100	Sheet Metal	No Correction
	50	TRKTRL	1.22+2.22	5.1		14.3	13.5	10.3	10.2	8.4			8.3	1200	Sheet Metal	No Correction
	51	TRKTRL	1.22+2.22	4.9		14.5	13.7	9.7	9.8	9			8.2	not paid at the time of data collection	Sheet Metal	No Correction
	52	TRKTRL	1.22+2.22	6.2		14.7	13.5	9.7	9.8	9			8.2	1200	Sheet Metal	No Correction
	53	TRKTRL	1.22+2.22	5.7		14.7	15	9.4	9.2	9			9.7	1450	Sheet Metal	No Correction
	54	TRKTRL	1.22+2.22	5.8		14.4	14	9.3	9.7	10			8.4	1250	Coil Sheet Metal	Rearranged
	55	TRKTRL	1.22+2.22	5.8		8.5	7.9	12.3	13.3	14			9.6	400	Container	No Correction
	56	TRKTRL	1.22+2.22	6.6		14.5	14	9.6	10	8.8			8.5	1250	Coil Sheet Metal	Rearranged
	57	TRK	1.22	7.3		12.8	12.4						5.2	700	Stone Charcoal	
	58	TRK	1.22	5.6		12.7	12.2						4.9	not paid at the time of data collection	Stone Charcoal	No Correction
	59	TRKTRL	1.22+2.22	5.5		14.8	14.8	9.6	8.2	8.4			9.6	1400	Coil Sheet Metal	Rearranged
	60	TRKTRL	1.22+2.22	7.1		14.9	13.3	11	10.5	10.6			10.3	400	Sesame	Offloaded
	61	TRKTRL	1.22+2.22	10		14.8	14.1	16.2	9.6	8.3			17.1	800	Container	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	62	SMTRL	11.22-2222	4.4	6	16.2	15.8	11.5	12	11.2	13.6		20.3	3000	Container	No Correction
	63	TRKTRL	1.22+2.22	5		15.4	14.3	8.4	10.2	10.6			10.5	500	Coil Sheet Metal	Rearranged
	64	SMTRL	11.22-2222	4.5	7	16	15.3	11.9	11.8	12.2	13		20.2	3000	Container	No Correction
	65	SMTRL	1.2-22	7.1		19	8.8	8.4					9	400	Container	No Correction
	66	TRKTRL	1.22+2.22	7		15.5	14.5	11.3	10.7	10.6			12.6	not paid at the time of data collection	Stone Charcoal	No Correction
	67	SMTRL	1.22-222	7.1		10.8	10	11.9	11.5	14.2			8.4	400	Sheet Metal	No Correction
	68	SMTRL	1.22-222	6.6		10.5	9.8	11.6	12	14.5			8.6	not paid at the time of data collection	Sheet Metal	No Correction
	69	TRKTRL	1.22+2.22	3.9		15.2	14.4	9.1	9.6	10.3			9.9	450	Coil Sheet Metal	Rearranged
	70	SMTRL	1.22-222	6.8		10.8	10.5	11.9	11.6	14.2			9	not paid at the time of data collection	Sheet Metal	No Correction
	71	SMTRL	1.22-222	6.8		10.8	10.5	11.9	11.6	14.2			9	1350	Sheet Metal	No Correction
	72	TRKTRL	1.22+2.22	7		10.8	10.5	9.9	11.2	15.6			8.1	1200	Sheet Metal	No Correction
	73	SMTRL	1.22-222	7.4		10.7	9.8	11.4	11.4	14.5			8	300	Sheet Metal	No Correction
	74	TRKTRL	1.22+2.22	7.1		14.5	14.9	10.7	11	10.4			11.5	365	Stone Charcoal	No Correction
	75	SMTRL	1.2-222	6.1		17	10.5	7.6	9.4				7.5	350	Container	No Correction
	76	TRKTRL	1.22+2.22	4.6		15	14.7	10.6	8.2	7.1			10.3	500	Coil Sheet Metal	Rearranged
	77	TRKTRL	1.22+2.22	9.7		16.5	15.3	15.3	11	10.8			20.6	2500	Container	No Correction
	78	TRKTRL	1.22+2.2	4.7		13.5	13.2	11.3	12.2				10.2	500	Wheat	Offloaded
	79	TRKTRL	1.22+2.22	7.1		16.6	16.2	11.5	11.2	12.3			17.8	800	Container	No Correction
	80	TRKTRL	1.22+2.22	8.1		14.3	14.2	10.1	11	9.7			9.7	400	Stone Charcoal	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	81	SMTRL	1.22-222	6.1		10	9.8	16.4	12.2	11.9			10.5	400	Sesame	Offloaded
	82	TRKTRL	1.22+2.22	7.6		14.7	13.4	11.3	8.6	8.1			9.4	400	Different Materials	Rearranged
	83	TRKTRL	1.22+2.22	8.5		15	15	12.5	9.9	9			12.5	600	Container	No Correction
	84	TRKTRL	1.22+2.22	5.1		16.2	16	11.2	10.6	10.1			14.1	2100	Stone Charcoal	No Correction
	85	TRKTRL	1.22+2.22	6.2		16.4	16.3	11.7	11.8	11.8			18	800	Stone Charcoal	No Correction
	86	SMTRL	1.22-222	6		11.4	11.5	14.3	15	14.5			16.7	600	Sheet Metal	No Correction
	87	SMTRL	1.22-222	5.8		12.7	12.6	13.6	12.4	16.2			17.5	700	Sheet Metal	No Correction
	88	SMTRL	1.22-222	6.2		12.6	12.4	13.4	13.4	17			18.8	not paid at the time of data collection	Sheet Metal	No Correction
	89	TRKTRL	1.22+2.22	9		13.6	13	10.8	11.6	11.4			11.4	500	Stone Charcoal	No Correction
	90	TRKTRL	1.22+2.22	6.6		15.6	14.8	10.5	9.5	9.7			10.9	not paid at the time of data collection	Coil Sheet Metal	Rearranged
	91	TRKTRL	1.22+2.22	6.5		14.3	14.2	11.6	9.8	10			10.1	400	Stone Charcoal	No Correction
	92	TRKTRL	1.22+2.22	6.5		14	13.9	6.7	6.5	8.9			7.9	not paid at the time of data collection	Container	No Correction
	93	TRKTRL	1.22+2.22	7.6		14.3	14.1	11	10	9.2			9.4	400	Container	No Correction
	94	TRKTRL	1.22+2.22	6.5		15	14.6	9.8	9.2	9.9			9.6	400	Coil Sheet Metal	Rearranged
	95	SMTRL	1.2-22	7.1		16.4	11.5	11.1					9	not paid at the time of data collection	Container	No Correction
	96	TRKTRL	1.22+2.22	8.5		14.6	14.7	11	10.5	10.4			11.7	not paid at the time of data collection	Stone Charcoal	No Correction
	97	TRKTRL	1.22+2.22	7.2		15.8	15.4	10.4	10.3	10.6			12.5	not paid at the time of data collection	Stone Charcoal	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load	
				F1	F2	R1	R2	R3	R4	R5	R6	R7					
	98	TRKTRL	1.22+2.22	8.3		14.6	14.4	10.8	10.4	10.9			11.4	400	Container	No Correction	
	99	TRKTRL	1.22+2.22	7.4		14.2	13.5	11.5	10.5	10			9.7	400	Stone Charcoal	No Correction	
	100	TRKTRL	1.22+2.22	6.9		15.7	14.6	10.8	10.3	10.5			12	500	Stone Charcoal	No Correction	
	101	TRKTRL	1.22+2.22	6.3		15	14	10	10.4	9.8			9.4	300	Container	No Correction	
	102	TRKTRL	1.22+2.22	6.5		14	13.4	9.6	11.5	9.4			8.9	300	Stone Charcoal	No Correction	
	103	TRKTRL	1.22+2.22	6.8		15.3	14.4	9.8	10.9	10.3			10.9	400	Stone Charcoal	No Correction	
	104	TRKTRL	1.22+2.22	7.3		14.3	13.6	8.7	11.3	9.8			9.2	700	Container	No Correction	
	105	TRKTRL	1.22+2.22	7		14.6	14.4	9.4	9.6	9.3			9	1350	Container	No Correction	
	106	TRKTRL	1.22+2.22	7		14.7	14.2	10.4	10.6	11.6			11.5	500	Stone Charcoal	No Correction	
	107	TRKTRL	1.22+2.22	6.3		15.1	15.2	11.3	11.5	10.6			14	not paid at the time of data collection	Stone Charcoal	No Correction	
	108	TRKTRL	1.22+2.22	8.5		15.5	15.2	12.1	9.7	12.4			15.2	not paid at the time of data collection	Stone Charcoal	No Correction	
November 23-29, 2015	109	SMTRL	1.2-22	6.6		18.5	8.9	9.4					8.5	400	Container	No Correction	
	110	TRKTRL	1.22+2.22	7		14.6	14.3	13.7	10.3	10.7			13.6	650	Sheet Metal	No Correction	
	111	SMTRL	1.2-22	6.5		17.8	12.6	12.5					12.9	1935	Container	No Correction	
	112	SMTRL	1.2-22	5.6		16.8	10.7	11.4					8.9	450	Container	No Correction	
	113	SMTRL	1.22-222	6.9		14.2	14.4	10	9.8	9.7			8.6	not paid at the time of data collection	Coil Sheet Metal	Rearranged	
	114	SMTRL	1.2-22	6		6.6	14	15					9	450	Container	No Correction	
	115	SMTRL	11.22-2222	4.5	6.2	13.8	13.2	11	9.9	10	14.2			12.2	not paid at the time of data collection	Container	No Correction
	116	SMTRL	1.2-22	6.1		6.6	16	16						12	600	Container	No Correction
	117	SMTRL	1.2-22	6.6		23	6.9	7						13	650	Container	No Correction
	118	TRKTRL	1.22+2.22	6.5		13	12.7	11.4	12.1	15.1				14.3	1245	Container	No Correction
	119	TRKTRL	1.22+2.22	7		15.6	14.8	11.9	9.5	9.2				12.3	600	Container	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	120	TRKTRL	1.22+2.22	6.2		14.2	14.3	8.9	9.8	9.6			8.5	400	Container	No Correction
	121	SMTRL	1.2-22	6.7		15	11.5	12					8.5	not paid at the time of data collection	Container	No Correction
	122	TRKTRL	1.22+2.22	6.4		14	14	9.3	9.6	9.5			8	not paid at the time of data collection	Container	No Correction
	123	TRKTRL	1.22+2.22	7.5		14	13.8	10.2	8.3	9			8	1200	Coil Sheet Metal	Rearranged
	124	TRK	1.22	5.6		15.4	15.6						11	550	Ceramic	Rearranged
	125	SMTRL	1.2-222	6.2		12.5	12.5	13	13				11	550	Container	No Correction
	126	SMTRL	1.2-222	6.6		13	12.7	11.7	11.7				9.1	450	Container	No Correction
	127	TRKTRL	1.22+2.22	6.8		14.5	13.5	9.6	9.5	9			8	400	Coil Sheet Metal	Rearranged
	128	SMTRL	1.2-22	7.8		17.2	11	11					9.2	450	Container	No Correction
	129	TRKTRL	1.22+2.22	7.4		15	14.7	12.8	10.3	11			13.8	700	Salt	Offloaded
	130	TRKTRL	1.2+2.2	7.8		17.1	9.9	9.6					7.1	1035	Container	No Correction
	131	TRKTRL	1.22+2.22	6.7		12.9	12	12.7	11.1	11.1			9.8	not paid at the time of data collection	Sheet Metal	No Correction
	132	TRKTRL	1.22+2.22	7.3		14.6	14.9	10.5	9.1	9.1			10	not paid at the time of data collection	Sheet Metal	No Correction
	133	TRKTRL	1.22+2.22	7.3		14.4	14.2	11.5	10	10.9			11	not paid at the time of data collection	Stone Charcoal	No Correction
	134	TRKTRL	1.22+2.22	5.6		15.6	14.4	8.3	6	7.9			10	500	Plywood	Offloaded
	135	TRKTRL	1.22+2.22	7.9		13.5	12.4	10.9	11.3	9.7			8.1	not paid at the time of data collection	Stone Charcoal	Rearranged
	136	TRKTRL	1.22+2.22	6.9		13.4	12.6	10.6	10.1	10.3			7	350	Stone Charcoal	No Correction

Management of Load Balance and Its Impact on Pavement Conditions

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	137	TRKTRL	1.22+2.22	6.8		14.6	13.6	10.2	10.6	9.2			9	450	Salt	Offloaded
	138	TRKTRL	1.22+2.22	6.5		12.8	12.8	16.4	12	9.4			14	not paid at the time of data collection	Machinery	No Correction
	139	SMTRL	1.22-222	5.3		14.4	14.3	10	10.5	10.5			9.7	not paid at the time of data collection	Plywood	Offloaded
	140	TRKTRL	1.22+2.22	6.3		15	14.5	11	9.6	10			10.5	not paid at the time of data collection	Stone Charcoal	Rearranged
	141	TRKTRL	1.22+2.22	7.4		14.2	13.5	10.4	10	10.5			8.6	1290	Stone Charcoal	Rearranged
	142	TRKTRL	1.22+2.22	6.5		14.5	13.6	11.7	9.3	9.6			9.8	not paid at the time of data collection	Sheet Metal	No Correction
	143	TRKTRL	1.22+2.22	6.4		13.1	12.7	13.6	8.2	8.5			9.4	not paid at the time of data collection	Sheet Metal	No Correction
	144	TRKTRL	1.22+2.22	7.2		12.7	11.7	8.8	11.6	15.8			11.8	1770	Salt	Offloaded
	145	TRKTRL	1.22+2.22	7.6		16.5	16	10	11.4	11.1			15	750	Container	No Correction
	146	TRKTRL	1.22+2.22	6.4		16	15	12	11	9.6			14	700	Container	No Correction
	147	SMTRL	1.22-222	4.5		12	12	12.5	12	15.7			14.2	700	Container	No Correction
	148	TRKTRL	1.22+2.22	7		13.8	13.5	13.9	8	8.9			11.2	550	Ceramic	Offloaded
	149	SMTRL	1.2-22	6.5		17.2	13.5	12.5					13.2	650	Container	Rearranged
	150	SMTRL	1.2-22	7.2		13.7	14	16					13.7	400	Container	No Correction
	151	SMTRL	1.2-22	5.8		14	12	13.4					9.4	not paid at the time of data collection	Container	No Correction
	152	TRKTRL	1.22+2.22	8		14.5	14.5	13	9.2	8.5			12	600	Salt	Offloaded
	153	SMTRL	1.2-22	5.4		18.3	10.8	9.5					9.1	not paid at the time of data collection	Container	No Correction

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge	Goods Type	Correction on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	154	TRKTRL	1.22+2.22	6.2		14.5	14	8.5	11.4	8.6			9.9	500	Stone Charcoal	Rearranged

Overload Charge and Corrections on Excess Load at Modjo Vehicle Weight and Size Control Stations

Date	It No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge (ETB)	Goods Type	Corrections on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
August 24-30, 2015	1	TRK	1.22	8		13.7	13						6.7	350	Sand	Offloaded
	2	TRK	1.22	7.2		12.9	13						5.9	500	Sand	Offloaded
	3	TRK	1.22	7.9		13.6	13.1						6.7	400	Sand	Offloaded
	4	TRK	1.22	7.8		13.3	13.4						6.7	370	Sand	Offloaded
	5	TRK	1.22	7.1		13.6	13.4						7	350	Sand	Offloaded
	6	TRK	1.22	7.4		13.8	13.9						7.7	300	Sand	Offloaded
	7	SMTRL	1.22-22	6.6		10.6	10.1	12.4	12.1				5.2	300	Container	No Correction
	8	TRK	1.22	7.1		13.7	13.9						7.6	400	Sand	Offloaded
	9	TRKTRL	1.22+2.22	5.9		13.9	14.4	11.5	9.5	8.3			9.8	900	Coffee	No Correction
	10	TRK	1.22	7.8		13.2	12.7						5.9	295	Sand	Offloaded
	11	TRK	1.22	7		13.3	13.3						6.6	400	Crushed Stone	Offloaded
	12	TRK	1.22	6.8		13.2	13.5						6.7	400	Sand	Offloaded
	13	TRK	1.22	7.5		12.9	13						5.9	300	Sand	Offloaded
	14	TRK	1.22	7.6		13.2	13.5						6.7	350	Sand	Offloaded
	15	TRK	1.22	6.7		13.2	13.1						6.3	360	Sand	Offloaded
	16	TRK	1.22	7.2		13.2	12.8						6	300	Sand	Offloaded
	17	TRK	1.22	7.2		13.7	13.7						7.4	350	Sand	Offloaded
	18	TRK	1.22	6.8		13.6	14						7.6	350	Sand	Offloaded
	19	TRK	1.22		7.2		14	14					8	not paid at the time of data	Sand	Offloaded

Management of Load Balance and Its Impact on Pavement Conditions

Date	It. No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge (ETB)	Goods Type	Corrections on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
														collection		
	20	TRK	1.22	6.4		13.9	13.9						7.8	400	Sand	Offloaded
	21	TRK	1.22	7		13.1	12.7						5.8	300	Sand	Offloaded
	22	TRK	1.22	7.1		13.6	13.4						7	350	Sand	Offloaded
	23	TRK	1.22	6.8		14.2	13.9						8.1	405	Sand	Offloaded
	24	TRK	1.22	7.2		13.4	12.9						6.3	300	Sand	Offloaded
	25	TRK	1.22	7.2		14	14						8	400	Sand	Offloaded
	26	TRK	1.22	7.2		12.5	12.7						5.2	260	Sand	Offloaded
	27	SMTRL	1.22-22	6.2		9.3	9.7	14	13.3				7.3	400	Container	No Correction
	28	TRK	1.22	8.5		13.6	12.9						7	350	Sand	Offloaded
	29	SMTRL	1.2-22	6		17.5	13.5	13.2					14.2	800	Cement	Offloaded
	30	TRK	1.22	7.4		14	14						8	400	Sand	Offloaded
	31	TRK	1.22	6.9		12.4	12.2						4.6	230	Sand	Offloaded
	32	TRK	1.22	6.5		12.6	13.1						5.7	285	Sand	Offloaded
	33	TRK	1.22	7		14	13.8						7.8	380	Sand	Offloaded
	34	TRK	1.22	6.9		12.9	12.8						5.7	285	Sand	Offloaded
	35	TRK	1.22	6.5		13.2	14						7.2	360	Sand	Offloaded
	36	TRKTRL	1.22+2.22	5.2		14.3	14.2	10.7	7.5	8.3			9.2	800	Coil	Offloaded
	37	TRK	1.22	7.1		13.6	13.5						7.1	355	Sand	Offloaded
	38	TRK	1.22	6		13.2	13.1						6.3	300	Sand	Offloaded
	39	TRKTRL	1.22+2.22	7.8		13	14.1	10.7	6.3	10.4			8.2	574	plywood	Offloaded
	40	TRK	1.22	6.7		14.5	12.8						7.2	350	Sand	Offloaded
	41	TRKTRL	1.22+2.22	6.7		13	12.9	10.5	7.6	8.5			6.4	320	Wheat	Offloaded
	42	TRK	1.22	7.3		13.7	13.4						7.1	350	Sand	Offloaded
	43	TRK	1.22	7		13.9	14						7.9	400	Sand	Offloaded
	44	SMTRL	1.2-22	7		13.6	11.4	11.5					6.5	500	Container	No Correction
	45	TRK	1.22	6		13.1	13.1						6.2	300	Sand	Offloaded

Management of Load Balance and Its Impact on Pavement Conditions

Date	It. No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge (ETB)	Goods Type	Corrections on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	46	TRK	1.22	7.8		13.5	13.2						6.7	335	Sand	Offloaded
	47	TRK	1.22	6.9		12.2	13.2						5.4	400	Gypsum	Offloaded
	48	TRK	1.22	6.8		13.6	13.4						7	350	Sand	Offloaded
	49	TRK	1.22	7.1		14	14						8	400	Sand	Offloaded
	50	TRK	1.22	7.4		13.7	14						7.7	400	Sand	Offloaded
	51	TRK	1.22	6.7		13.1	13.1						6.2	400	Sand	Offloaded
	52	TRK	1.22	6.8		13.6	12.9						6.5	500	Sand	Offloaded
	53	TRKTRL	1.22+2.22	6.7		15	14.7	7.5	5.3	4.7				9.7	700	Container
September 23-29, 2015	54	TRK	1.22	6.8		13	13						6	300	Stone	Offloaded
	55	TRK	1.22	7.1		13.6	14.1						7.7	385	Sand	Offloaded
	56	TRK	1.22	7		13.9	13.9						7.8	380	Sand	Offloaded
	57	TRK	1.22	7		14.1	13.9						8	400	Sand	Offloaded
	58	SMTRL	1.22-22	5.9		11.8	12	15.3	14.9				14	1000	Container	Offloaded
	59	SMTRL	1.2-22	6.1		13.5	13.3	13					9.8	490	Container	Offloaded
	60	TRK	1.22	6.8		14.1	14						8.1	not paid at the time of data collection	Sand	Offloaded
	61	TRK	1.22	6.8		14.4	14.2						8.6	430	Sand	Offloaded
	62	TRK	1.22	8		14.1	14.6						8.7	400	Sand	Offloaded
	63	TRK	1.22	7.3		14	13.6						7.6	380	Sand	Offloaded
	64	TRK	1.22	7.2		14.2	14.4						8.6	450	Sand	Offloaded
	65	TRK	1.22	7		14.1	13.9						8	400	Sand	Offloaded
	66	TRKTRL	1.22+2.22	8		13.6	14	10.8	9.4	9.7			8.4	800	Container	Offloaded
	67	TRK	1.22	7.1		14.2	14.3						8.5	400	Sand	Offloaded
	68	TRK	1.22	7.5		14.1	14.2						8.3	400	Sand	Offloaded
	69	TRK	1.22	7		14	14						8	400	Sand	Offloaded
70	TRK	1.22	7.4		14.5	14.1						8.6	430	Sand	Offloaded	
71	TRK	1.22	7.2		13.7	13.8						7.5	380	Sand	Offloaded	
72	TRK	1.22	7.6		13.9	13.8						7.7	350	Sand	Offloaded	
73	TRK	1.22	6.8		14	14						8	400	Sand	Offloaded	
74	TRK	1.22	7.3		14.3	14.2						8.5	420	Sand	Offloaded	

Management of Load Balance and Its Impact on Pavement Conditions

Date	It. No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge (ETB)	Goods Type	Corrections on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	75	TRK	1.22	6.7		14.2	14						8.2	400	Sand	Offloaded
	76	TRK	1.22	8		13.5	13.5						7	350	Sand	Offloaded
	77	TRK	1.22	6.3		14	13.9						7.9	400	Sand	Offloaded
	78	TRK	1.22	7.4		14	14						8	not paid at the time of data collection	Sand	Offloaded
	79	TRK	1.22	7.4		13.8	13.8						7.6	380	Sand	Offloaded
	80	TRK	1.22	7.1		13.8	13.5						7.3	380	Sand	Offloaded
	81	TRK	1.22	6.4		13.6	14.3						7.9	350	Sand	Offloaded
	82	TRK	1.22	6.1		14.4	14.3						8.7	440	Sand	Offloaded
	83	TRK	1.22	7.1		14	14.1						8.1	400	Sand	Offloaded
	84	TRK	1.22	7.5		13.7	13.6						7.3	350	Sand	Offloaded
	85	TRK	1.22	6.6		13.8	13.8						7.6	380	Spare Part	No Correction
	86	TRKTRL	1.22+2.22	8		14	14.5	10.9	9	10.9			10.3	700	Container	Offloaded
	87	TRKTRL	1.22+2.22	6.5		13.6	13.4	9.8	8.2	9.7			7	350	Wheat	Offloaded
	88	TRKTRL	1.22+2.22	4.1		12.5	12.7	9.5	8.2	8.6			5.2	520	Wheat	Offloaded
	89	TRK	1.22	7		13.7	13.8						7.5	380	Sand	Offloaded
	90	TRKTRL	1.22+2.22	7		13.6	13.4	9.5	8.3	8.8			7	not paid at the time of data collection	Wheat	Offloaded
	91	TRKTRL	1.22+2.22	6.5		12.4	12.8	9	8.9	9.8			5.2	400	Wheat	Offloaded
	92	TRK	1.22	7.3		13.7	14						7.7	not paid at the time of data collection	Crushed Stone	Offloaded
	93	TRK	1.22	6.9		13.8	13.7						7.5	500	Wheat	Offloaded
	94	SMTRL	1.22-222	7.1		12.6	13.5	4.8	8.4	9.1			6.1	300	Wheat	Offloaded
	95	TRK	1.22	7.4		13.9	13.4						7.3	370	Sand	Offloaded
	96	TRK	1.22	7		14	14						8	400	Sand	Offloaded

Management of Load Balance and Its Impact on Pavement Conditions

Date	It. No.	Vehicle Type	Axle Configuration	Axle Load (Tonnes)									Total Overload (Tonnes)	Overload Charge (ETB)	Goods Type	Corrections on Excess Load
				F1	F2	R1	R2	R3	R4	R5	R6	R7				
	97	TRK	1.22	7.8		14	13.9						7.9	not paid at the time of data collection	Sand	Offloaded
	98		1.22-22	6		8.1	7.7	13.7	13.8				7.5	750	Container	Offloaded
	99	TRK	1.22	6.4		13.8	14						7.8	400	Sand	Offloaded
	100	TRK	1.22	7.5		14.1	14.4						8.5	425	Sheet Metal	Offloaded
	101	TRK	1.22	7.4		14.5	14.5						9	450	Sand	Offloaded
	102	TRK	1.22	7.8		14	14						8	400	Sand	Offloaded
	103	SMTRL	1.22-222	6.4		10.5	10.2	10.7	14.1	13.9			9.4	940	Container	Offloaded
	104	TRK	1.22	7.3		14	14						8	400	Sand	Offloaded
	105	SMTRL	1.22-222	6.4		12.4	12.2	10.1	11.1	10.5			6.3	630	Container	No Correction
	106	SMTRL	1.22-222	7.1		12.5	12.2	7.9	11.2	12.4			8.3	830	Container	Offloaded
	107	TRK	1.22	7.8		15.1	15.4						10.5	500	Sand	Offloaded
	108	TRK	1.22	7.2		14.2	14.4						8.5	430	Sand	Offloaded
	109	TRK	1.22	7.3		13.5	13.5						7	350	Sand	Offloaded
	110	TRK	1.22	7.6		14.1	14.4						8.5	430	Sand	Offloaded
	111	TRK	1.22	6.3		14.2	14.5						8.7	450	Sand	Offloaded
	112	TRK	1.22	7.2		14	14.1						8.1	400	Sand	Offloaded
	113	TRK	1.22	7.2		13.9	14						7.9	400	Sand	Offloaded
	114	TRK	1.22	7.3		14.1	14						8.1	410	Sand	Offloaded
	115	TRK	1.22	7.7		12.7	12.9						5.6	300	Sand	Offloaded
	116	TRK	1.22	7.5		14	13.6						7.6	not paid at the time of data collection	Sand	Offloaded

Annex-4

Sample Questionnaire

Target Group

- Pavement Engineers

Instructions

Please answer all questions to the best of your knowledge and when an explanation is needed- please be informative.

1. Gender:

Male

Female

2. Age:

20-25

26-35

36-50

50+

3. Educational Qualification:

Certificate

Diploma

B.Sc. Degree

M.Sc Degree

PHD

4. Profession/Study Area: _____

5. Work Experience in Road Sector:

Less than 1 year

2-5 years

5-10 Years

10+

6. Do you think that the axle load survey data collected by ERA is correct?

Yes

No

7. Which axle load survey data do you used for road design projects?

Axle load survey data collected by your team

Axle load survey data collected by ERA

Mixed

8. Which equivalent factor do you consider to convert traffic volumes to equivalent single axle load (ESA)?

- Mean equivalent factor from more heavily trafficked lane
- Mean equivalent factor from less trafficked lane
- Average equivalent factor of the two lanes
- Equivalent factor from legal axle load limit

9. Do you have any different consideration for more heavily trafficked lane along Addis Ababa – Djibouti route or any other import export route during design and construction stage?

Yes

No

If your answer is yes, what are the considerations / If your answer is no, why? _____

Target Group

- Drivers

Instructions

Please answer all questions to the best of your knowledge and when an explanation is needed- please be informative.

1. Gender:

Male

Female

2. Age:

20-25

26-35

36-50

50+

3. Work Experience:

Less than 1 year

2-5 years

5-10 Years

10+

4. Are you responsible to protect roads from failure due to overloading?

Yes

No

5. Do you know the difference between Gross Vehicle Weight and Axle Load Weight?

Yes

No

6. Which one is used in the axle load control station for controlling system?

Gross Vehicle Weight

Axle Load Weight

7. How much is the legal axle load limit for front and rear axle separately in tonnes?

8. If you are experienced with overload, what are the measures taken by axle load control stations?

- Offload or Rearrange
- Overload Charge
- Both
- No measure

9. Is the measures taken by axle load control station on overloaded vehicles are transparent and depends on the regulation?

- Yes No

Target Group

- Vehicle Weight and Size Control Team and Station Staff

Instructions

Please answer all questions to the best of your knowledge and when an explanation is needed- please be informative.

1. Gender:

- Male Female

2. Age:

- 20-25 26-35 36-50 50+

3. Educational Qualification:

- Certificate Diploma B.Sc. Degree
M.Sc Degree PHD

4. Work Experience in vehicle weight and size control station:

- Less than 1 year 2-5 years 5-10 Years 10+

5. Do you permit tolerance for overloaded vehicles?

- Yes No

How much? _____

6. What do you do when the weighbridge is malfunction?

- Leave the vehicle without weighing
Use Mobile weighbridge

7. Is there any probability that overloaded vehicles travel further without correct the excess load?

Yes

No

Why? _____

8. Is there any probability that vehicles can violate the rule and pass without weighing?

Yes

No

Thank you for your help!

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