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Trends and Impacts of Traffic Loading on The Northern Corridor Athi River – City Cabanas Highway Section, Kenya

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Declaration

This thesis is my original work and has not been presented for a degree in any other university

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Dedication

This Research is dedicated to my lovely Parents Rev. James Odede Athuok and Mrs. Rosemary Adhiambo Odede.

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Lastly, I wish to thank my family and friends for their love and support all this time.

Abstract

Deterioration of roads is among the major challenges facing Kenya's infrastructure sector. Pavement deterioration is mainly caused by traffic overloading and erratic climatic conditions. The Mombasa-Nairobi Highway known as A109 / A8 is a section of the Northern Corridor that connects Kenya's three major cities: Mombasa, Nairobi, and Kisumu and links the port of Mombasa to the entire East and Central Africa region. The road plays a major role in the region's economy by facilitating transportation to landlocked countries from the port of Mombasa. It is prone to premature deterioration in most of its sections. Overloading of vehicles consisting of local trucks mostly supplying building materials and long-distance heavy goods vehicles from the port of Mombasa to other East African countries is suspected to be a major cause of the premature deterioration which increases the pavement maintenance costs.

This study investigated the trends and impact of traffic loading along the Northern Corridor Athi River - City Cabanas highway road section. The impact of overloading was determined from the remaining service life of the pavement due to overloading. Axle load measurements were carried out using a static axle weighing machine and mobile weighing machine along with visual inspection of the study section. The remaining service life of the pavement when subjected to overloading was estimated and compared to the pavement design service life. The fourth power rule was used to obtain the vehicle damaging factor which is a factor used to assess the extent of pavement destruction by a vehicle. The behaviour of transporters along the road section was also assessed by the use of questionnaires. The questionnaire investigated the transporters' knowledge of axle load limits, penalties and why the transporters still overload despite the measures to curb overloading

Mombasa bound traffic was found to be prone to overloading with mobile weighbridge having the highest overload case. This led to an average of two years on the remaining service life of the pavement designed to last for fifteen years. The reduction in pavement service life leads to increased maintenance costs as the road will require major rehabilitation before the projected service period elapses. This, therefore, calls for the government to conduct mass education to inform transporters of the limits and penalties of overloading. The government in conjunction with truck manufacturers should also come up with better guidelines and regulations for truck body designs and axle configuration and direct SACCOs and transport companies to provide truck weighing machines at loading points to help verify gross vehicle weight.

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List of Abbreviations

KeNHA	Kenya National Highways Authority
RDM, Part III	Kenya Road Design Manual Part III
JICA	Japan International Cooperation Agency
IRI	Internal Roughness Index
UNECA	United Nations Economic Commission for Africa
EAC	East African Community
NCTTA	Northern Corridor Transit and Transport Agreement
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
SN	Structural Number
PSI	Present Serviceability Index
MoRPW	Ministry of Roads and Public Works
KRB	Kenya Roads Board
NTSA	National Transport and Safety Authority
NCTTCA	Northern Corridor Transit and Transport Coordination Authority
WIM	Weigh-in-Motion
ANPR	Automatic Number Plate Recognition
VWB	Virtual Weighbridge
IDA	International Development Association
RMLF	Road Maintenance Levy Fund
PBMC	Performance-Based Road Maintenance Contracting
KTSSP	Kenya Transport Sector Support Project
TRL	Transport Research Laboratory
CESA	Cumulative equivalent standard axle

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study Problem

Roads are designed to handle a specified amount of load imposed by traffic over their design life. Since traffic consists of vehicles with different configurations and different axle loads of varying magnitudes, the loads that can be sustained are quantified in terms of repetitions of equivalent standard axles. The cumulative equivalent standard axles over the pavement design life are projected and used to design the pavement as per the expected load repetitions over its design life. An overloaded vehicle's equivalent standard axle is higher than the standard vehicle of a similar configuration used in the design. For a road frequented by vehicles that are overloaded, the cumulative number of equivalent standard axles projected in the design is reached before the pavement design period elapses leading to premature pavement failure which results in increased maintenance costs.

From a previous study employing mobile weighbridges along the Northern Corridor, Mombasa-Nairobi section twenty-five to fifty percent of axles in the Mombasa – Nairobi Direction were overloaded. Extremely overloaded axles of two hundred kilonewtons were also measured. (Ministry of Transport and communication, Republic of Kenya, 1987). Overloading increases pavement maintenance costs by introducing pre-mature failure and by reducing the life span of the road and has continued to be rampant on the Northern Corridor despite the installation of various static weighbridges at Mombasa port, Mariakani, Athi River (Mlolongo), Gilgil, and Busia.

Despite being clear that overloading is a cause of the premature pavement failure on the section under study, there is a lack of studies that quantify the effect on pavement life as a result of overloading. This research analyses and quantifies the impact of overloading on pavement life. The reasons for continued overloading despite the various measures that have been put in place were also analysed and it is projected that these will help in the formulation of policy to better deal with the problem.

1.2 Problem Statement

The life span of a road is greatly affected by the number of standard design axle loads it's able to bear before giving in. Overloading not only increases maintenance costs of the roads by introducing premature failure but also reduces the anticipated life span of the road at design. This leaves axle load control as the first step to road maintenance.

Despite the introduction of weighbridges, overloading still goes on. The Kenyan Government spends large sums of money on the repair of roads that have been damaged by overloading. A lot of money is put annually into the maintenance of the deteriorated roads. This money could have been used in other development and essential infrastructural projects, but instead, it goes to maintenance and therefore leading to an infrastructural deficit. Some of the causes associated with deterioration are corruption by the weighbridge officials and dispersion of the weighbridges over long distances. (Mulipi, 2016).

The rise in unplanned road maintenance costs and premature damage, therefore, called for analysis of the current loading data, to determine the trends of axle loadings and to quantify the impact of overloading on pavement service life. This will aid in coming up with solutions that address pavement deterioration as a result of overloading. It was also necessary to talk to transporters to determine the level of awareness and general attitudes towards axle load control to enable the solutions to overloading to be more inclusive. By studying the trends and impacts of overloading, the relevet agenecies can be able to come up with better policies to address overloading and come up with measures that mitigate pavement deterioration due to overloading.

1.3 Objectives of the Study

1.3.1 The Main Objective of the Study

To investigate traffic loading trends on the Northern Corridor, Athi River to City Cabanas section and to assess the impact of overloading on pavement service life.

1.3.2 Specific Objectives of the Study

i. Measure traffic axle load data at Mlolongo static weighbridge and mobile weighbridge, analyse the data to identify overloading.

ii. Examine the financial implications of pavement deterioration.

iii. Evaluate the impact of overloaded axles on the pavement by visual analysis of the pavement along the section under study.

iv. Assess transporters' awareness of axle load limits, their views on overloading and penalties for overloading, and reasons for continued overloading despite measures implemented to curb overloading.

1.4 Research Questions

The research questions listed below, provided a guideline during the study and analysis on the overloading trends, reasons for overloading, and ways to effectively curb overloading to fully get the designed level of service during operation of the road;

i. What are the current trends of overloaded axles from the current weighbridge axle load data and mobile weighbridges?
ii. What is the impact of overloading on pavement life?
iii. What are the financial implications of premature road failure due to overloading in terms of road maintenance and rehabilitation costs?
iv. What is the impact of overloading axles on the pavement identifiable using visual analysis as pavement distress and deterioration along the section under study?
v. What are transporters' views on overloading and penalties and why do they still overload despite measures to curb overloading?

1.5 Study Justification

Unregulated traffic loading leads to premature pavement failure through, cracking, rutting, formation of potholes, and bitumen bleeding which makes the roads unsafe. Overloaded vehicles tend to cause traffic snarl-ups on road sections where there are no climbing lanes and are prone to accidents while descending steep slopes leading to loss of lives and even damage to road furniture. Premature pavement deterioration causes unplanned maintenance costs on these road sections and sometimes full rehabilitation is required. The purpose of this study was to analyse overloading trends and assess the impact of axle overloading on pavement deterioration. With information on deterioration as a result of overloading, it's possible to take measures to mitigate premature pavement deterioration. Measures such as accounting for the effects of overloading on pavement life can be incorporated in designs since it is impossible to totally mitigate overloading.

Although the government has come up with ways of curbing overloading by for example introducing weighbridges and imposing fines on the overloaded trucks, transporters still overload, and hence, getting to know why this still happens is an integral part of the study. Information from this study will help in formulating measures targeted specifically to the transport industry. This will help curb overloading and its effects leading to more benefits being gained from investment in road infrastructure. From this study, amounts spent on unplanned road maintenance that have prematurely deteriorated due to overloading could be used in other essential development and bridging infrastructural deficit.

The data collected from this study has the potential to raise awareness and to lead to a better understanding of the real cause and effects of overloading, and hence help to come up with measures and recommendations that will help to solve the situation. In so doing, the road authorities will benefit since they will be able to come up with policies and actions that are more favourable and that are achievable to solve the challenge, the transporters will be more willing to adhere to the limits provided, the maintenance costs on the roads will reduce, and the government and the society at large will also benefit since other infrastructural projects would also be considered and in turn lead to the development of the economy.

1.6 Scope and Limitations of the Study

1.6.1 Scope of the Study

The study covered a section of the Northern corridor from Athi River interchange to the City cabanas. Axle load data was limited to the above section including data obtained from the Mlolongo static weighbridge. Data from the mobile weighbridges was limited to the approaches to and from the Mlolongo weighbridge. However, studies on the pavement sections with deteriorated surface conditions due to overloading and maintenance costs covered other sections along the Mombasa and Nairobi highway. Plate 1-1 below shows the Athi River interchange to the City cabanas section of the Northern corridor and the Mlolongo weighbridge where loading data was obtained:

Plate 1-1: Study Area

Source: Google Maps, 2020

1.6.2 Limitations of the Study

During the study, axle load data collection was done electronically both for the static and mobile weighbridge which streamlined the process. Challenges were however encountered in the questionnaire data collection as

i. Language barrier – Since the northern corridor is an international passageway, there were drivers from multiple countries. Some drivers did not speak any English and hardly any Swahili. This made the data collection exercise challenging due to communication difficulty.

ii. Some drivers were apathetic to the interviews and hence gave incomplete information.

iii. The study section was limited to sections of the northern corridor with both static and mobile weighbridge machines as the machines are immovable and the mobile weighing machines are very expensive to hire.

iv. The mobile weighbridge only weighed trucks that visually seemed to be overloaded and were evading the main static weighbridge. Overloaded trucks using other routes might have not been captured.

CHAPTER TWO: LITERATURE REVIEW

2.1 The Northern Corridor

The Northern Corridor is a multimodal commerce route that connects the Great Lake Region's landlocked countries with Mombasa, Kenya's marine seaport. The Northern Corridor Transit and Transport Agreement (NCTTA) is a treaty with 11 protocols signed in 1985 and amended in 2007 for regional cooperation with the goal of promoting interstate and transit commerce between Burundi, DRC, Kenya, Rwanda, and Uganda. In 2012, South Sudan ratified the Agreement. (The Northern Corridor Transit and Transport Coordination Authority, 2020). The major objectives of the Northern Corridor Transit and Transport Agreement were:

i. Sustainable transport, which in return would economically help in promoting efficient and competitive transport in terms of cost.
ii. The Social pillar to foster an all-inclusive transport system with fully equipped stations and terminals, and finally
iii. The Environmental pillar to promote green freight transport and encourage the use of renewable sources of energy.

This thesis research focused on the first objective by investigating the impact that the traffic loads had on the road asset and the trends of vehicular loading to ascertain whether the pavement was being used sustainably.

The Northern Transit corridor spans East and Central African countries as depicted in Figure 2-1 below:

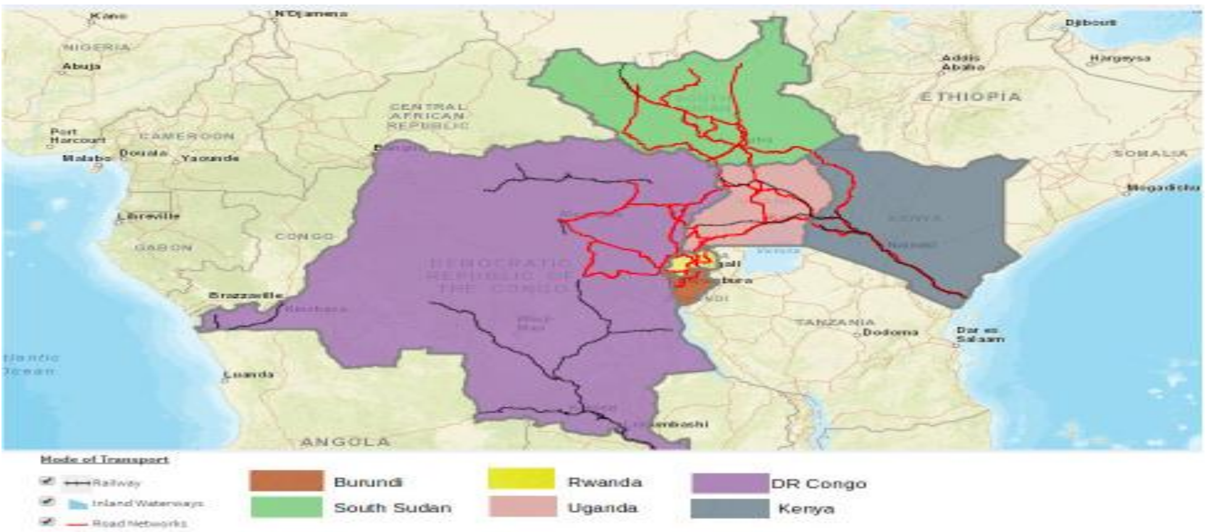


Figure 2-1: Northern Corridor Member States

Source: (The Northern Corridor Transit and Transport Coordination Authority, 2020)

2.1.1 Mombasa – Nairobi Section

The study section, Athi River interchange to City Cabanas forms part of the Mombasa – Nairobi highway majorly known as A109 which links Kenya's capital to the East African Largest port of Mombasa. The 482 km road bears heavy traffic due to freight transportation from the port into the mainland and to other neighbouring landlocked countries. The road has failed to handle the current traffic capacity at some sections and a proposal for expansion to a six-lane superhighway is ongoing by the government.

Of interest to this study was the traffic loading trends along the corridor since overloading is one of the major causes of pavement deterioration along the Northern Corridor. According to the axle load distribution study in one of the sections of the Northern corridor (Between Mombasa and Nairobi) done between 1976 and 1980, 25%-50% of the axles were overloaded in the Mombasa – Nairobi Direction. The study also revealed that between 3% and 14% of the weighed vehicles had overloads that exceeded 130kN. Extremely overloaded axles of 200kN were also measured. In the other direction, 5% to 22% of the axles were observed as overloaded and less than 5% exceeded 130kN (Ministry of Roads and Public Works, 1988)

This study focused on the Athi River interchange to the City Cabanas section. This section is prone to overloading despite the existence of the Athi River (Mlolongo) weighbridge. Overloading is one of the causes of pavement deterioration leading to the higher maintenance costs of the sections of the Northern Corridor. Heavy goods vehicles ply the section and form a large part of the traffic as shown in Plate 2-1 below.

Plate 2-1: A section of the Nairobi – Mombasa road (traffic snarl-up at Athi River, Mlolongo weighbridge).

Source: (The Northern Corridor Transit and Transport Coordination Authority, 2020)

2.1.2 Pavement Rehabilitation Criteria for the Northern Corridor

The Northern Corridor is made up of 99% flexible pavement which follows the AASHTO guidelines for flexible pavement design. During design, the thicknesses of each layer making the pavement has a specific drainage coefficient that is used to generate the structural number which defines the strength of the overall pavement (AASHTO, 1993). Once the appropriate drainage coefficients have been plugged in the structural number equation, suitable thicknesses for each pavement layer can be determined (AASHTO, 1993). This AASHTO method can also be used to evaluate existing pavements. For example, taking into consideration a pavement in need of rehabilitation and maintenance, the existing layer thicknesses could be used in determining a Structural Number for the existing pavement layer. This can then be compared with the pavement number for the updated design to indicate the type and thickness of rehabilitation required.

2.1.2.1 Traffic Loading, Vehicle Equivalence Factors

The AASHO Road Test is a systematic experiment that was performed to express the relationship between the axle load and the damage that the load causes to the road (Moreno, Resources, 2000). The experiment was first carried out in Illinois, USA, where vehicles of various axle loads were allowed to travel on different sections of a newly built road to determine the impact of their axle loads on the pavement. The experiment was carried out between 1956 and 1960 where several processes for comparing the number of load repetitions that the vehicles imposed on the road and the resultant distress in the pavement were carried out (Moreno, Resources, 2000). The relationship between the axle load and the distress in the pavement was expressed by Equation 2-1.

$$A_{EQ} = \left(\frac{AL}{8.16}\right)^n \qquad (2\text{-}1)$$

Where;

A_{EQ}	The equivalence factor for an individual axle load
AL	The measured axle load
n =	4.2

The formula is used to compare the damaging effect of any axle load on the pavement structure to the damaging effect of a standard axle load of 80kN (8.16 tons). The Equivalence Factor enables the conversion of vehicle configurations and axle loads of any type into an equivalence of the standard axle (Moreno, Resources, 2000). The relationship between the axle load and the damaging effect is exponential. Previous axle load surveys on the Northern Corridor have shown that there is overloading of trucks that transport goods from the port of Mombasa to various destinations. The vehicle equivalence factors for all types of vehicles can be calculated by adding the equivalence factors for individual axle loads using equation 2-2.

$$V_{EF} = \sum_{i=1}^{N} A_{EQ(i)} \qquad (2\text{-}2)$$

Where;

A_{EQ}	The equivalence factor for an individual axle load
N	the total number of axles for an individual vehicle

Table 2-1 below shows the standard vehicle equivalence factors for the various vehicle axle configurations that were studied.

Table 2-1: Vehicle Equivalence Factors for the various vehicle axle configurations

Vehicle Type	$\boldsymbol{V_{EF}}$
2-axle (2A)	3.898
3-axle (3A)	3.679
4-axle (4A)	5.934
6-axle (6A)	6.003

Source: (Jacob, 2020)

2.2 Traffic Distribution on the Northern Corridor

Before the construction of the Standard Gauge Railway, 99% of the goods imported through the port of Mombasa were transported via the Northern Corridor to various destinations in the East and Central Africa region (JICA, 2017). The section of the road was majorly occupied by heavy trucks transporting goods from the port of Mombasa, which consisted of over 65% of the total number of vehicles that use the corridor (JICA, 2017). The Nairobi-Mombasa road section is mostly congested at specific points where traffic from other feeder roads coincide (NCTTCA, 2021). These include town centres along the corridor, at weighbridges and due to other traffic incidents, such as accidents or wildlife from national parks blocking the road. Public transport vehicles and personal cars have also increased in number over the years on the corridor especially during holiday seasons as the coastal region is a major tourist attraction where many people go to spend their holidays (NCTTCA, 2021).

2.2.1 Traffic Forecast

Traffic forecasting is an important element for the efficient development of road networks in a country. The simulation of traffic distribution data is based on the user equilibrium model which implies that the time spent on a trip is a result of traffic incidents at other sections of the road or the road network (Nicholas & Lester, 2009). The driver has to choose a particular route depending on the time spent on the route as a result of delays on the route. Models of traffic forecasting follow a given procedure in the calculation of the expected volume of traffic on a particular road for a given period (Nicholas & Lester, 2009).

The first step involves the preparation of baseline information about the road or the road network and the performance. The baseline information is also prepared for the terminal servers and characterization of the distribution of the transportation demand is done (Nicholas & Lester, 2009).

The next step involves the input of data about the transportation demand of the road and road network and the characteristics that are necessary for evaluation (Nicholas & Lester, 2009). During input of the data, the first case involves the input of mobility plans that represent information on traffic demand on the road. This data is either entered manually or generated automatically from the results of field studies previously conducted. The second case involves the design of mobility plans using the model calculations. Most domestic traffic forecasting models utilize the computational methods as it offers a high degree of detail (Nicholas & Lester, 2009).

In the third step, the traffic demand distribution for the road is defined throughout the transport network. This is because developing and improving the performance of a road creates additional demand for the road network and leads to the redistribution of transportation demand that improves the performance of the road (Nicholas & Lester, 2009).

In the fourth step, the results of the model calculation are analysed for various purposes depending on several aspects such as the overall performance of the improved road capacity and the design phase. In this step, the designer transitions the hourly traffic to daily annual traffic designs cartograms of distributing traffic on the road and calculates the average travel distances and travel times (Nicholas & Lester, 2009). This step supports the simulation of traffic distribution and allows the design team to obtain data that is necessary for determining the optimal variant of the road and road network. The step also allows designers to justify the decisions made at various stages of the design process.

According to the Kenya Roads Design Manual Part III, 1987, when accurate traffic data is not available for traffic forecasting purposes during road design, the rate of growth of a country's GDP and GNP can be used for traffic forecasting (Ministry of Transport and Communication, 1987). According to the Central Bank of Kenya, the rate of growth of the GDP for Kenya is as illustrated in Table 2-2:

Table 2-2: Kenya's GDP Growth

Year	**Annual GDP growth (%)**
2018	6.30
2017	4.90
2016	5.90
2015	5.70
2014	5.40

Source: (Central Bank of Kenya, 2020)

The growth rate factors are used to calculate the cumulative standard axles for maintenance and rehabilitation of a pavement.

The Kenya Roads Designs Manual Part III, 1987 stipulates equation 2-3 for the calculation of the cumulative number of standard axles for a given road over a given period (Ministry of Transport and Communication, 1987);

$$T = 365t_1 \frac{(1+i)^N - 1}{i} \qquad (2\text{-}3)$$

Where;

t_1 Is the average daily number of standard axles recorded in the first year of opening the road to use.

i is the annual growth rate in the number of standard axles expressed in the form of a decimal fraction.

N is the number of years the road is being designed for (period)

2.3 Pavement Deterioration

Pavements deteriorate due to the influence of excess traffic loads and environmental factors. Excess loading causes the pavement layers to deflect (Babu, 2016). Pavement failure causes decreasing serviceability of the road due to the development of ruts and cracks on the road surface. Bituminous pavement failures occur as a result of a combination of factors ranging from vehicle axle loads and environmental factors. A pavement’s lifespan is enhanced if its surface is rehabilitated on time (David Rys, Jozef Judycki & Piotr Jaskula, 2016). The major factors considered in the maintenance of pavements include pavement cracking, rutting and the unevenness index. There are also several methods for the preservation of pavements that help in prolonging the life span of the road and delaying extreme pavement failure that will render the road impassable.

The level of a pavement’s distress is an indicator of its serviceability (AASHTO, 1993). Once collected, data about the road surface defects can be used to determine indices that classify the functionality of a road. The indices used to quantify a roads serviceability include the Pavement Serviceability Number and the Internal Roughness Index (IRI) (AASHTO, 1993).

The Pavement Serviceability Number is a metric that measures how well a pavement serves its users, particularly in terms of the road's surface quality. It's calculated by applying the user's rating scale to road sections in various stages of distress. Pavement is rated on a scale of 0 to 5, with 0 being the worst condition and 5 representing fresh or almost new pavement (Ministry of Transport and Communication, 1987).

The Internal Roughness Index (IRI) is calculated as a percentage of the vehicle's total suspension motion divided by the distance traveled during the test (AASHTO, 1993). It's a statistical indication of imperfections in the pavement surface that have a negative impact on ride quality, safety, vehicle maintenance, and operating expenses, and it specifies the longitudinal wheel track's profile (AASHTO, 1993). The recommended units for IRI are metres per kilometre (m/km). Millimetres per kilometre (mm/km) can also be used as a unit for IRI. The real profile of a newly built road represents a state defined by its IRI with an approximate range of 1-2.5 m/km. A recently constructed road's true profile indicates a state specified by its IRI, which has a range of 1-2.5 m/km. Pavement roughness fluctuates as traffic increases after the road is built, progressively raising pavement IRI values (AASHTO, 1993).

2.3.1 Factors Influencing Pavement Performance

i. Traffic - Loading magnitudes, load repetitions and different load configurations from heavy vehicles have a significant impact on pavement performance. The expected loadings are incorporated in the road design and repeated loading above the design load leads to premature pavement failure (Ministry of Roads and Public Works, 1988).

ii. Water – Ingress of water into the subgrade causes it to weaken. If extreme loads are applied on a pavement whose subgrade has been weakened by water, then failure occurs in the pavement and may manifest in ways such as heaving or reflective cracking (Ministry of Roads and Public Works, 1988).

iii. Construction procedures – Degree of compaction, moisture content during construction, quality of materials making the pavement layers and layer thickness are some of the factors affecting the durability of the pavement. If a pavement whose construction is substandard is subject to overloading, then it is expected that premature failure will occur (Ministry of Roads and Public Works, 1988).

iv. Subgrade – This is the underlying layer of soil beneath the pavement that supports other layers of the pavement and supports axle loads. Pavement failure and flexure originate from the subgrade when the subgrade becomes too weak to support the wheel loads. Overloading on a pavement may lead to excessive flexure in the subgrade leading to pavement failure. Excessive loads on an improperly compacted subgrade may also lead to heaving causing failure (Ministry of Roads and Public Works, 1988).

2.3.2 Vehicle Weight Vs Road Damage Levels

The bearing capacity of a pavement is influenced by the type of traffic it accommodates, the environmental conditions of the adjacent area, the quality of the pavement construction as well as the routine pavement operational and maintenance practices (O'Flaherty, 2007). Pavement deterioration is inevitable but its severity can be controlled through proper operational and maintenances practices (Thom, 2014). Overloading is a major cause of pavement deterioration thus should be strictly curbed. The Northern Corridor serves the Eastern and Central African region thus it is subject to very heavy traffic (NCTTCA, 2021). Charges for using a road differ mainly according to the extent of pavement destruction caused by the variations in vehicle axle loads. The level of road damage caused by a certain axle load may be determined using a criteria that dates back to the late 1950s AASHO road test (Arnold, 2017). According to the study, doubling an axle load does not have a linear impact, i.e., damage grows as a power function with an exponent of 4, thus doubling the weight can cause 2 to the power 4 more damage, or 16 times the damage (Arnold, 2017). The 'Fourth Power Law' is the name given to this phenomena.

In a paper (Newton & Ramdas, 2009) targeted at analyzing the Fourth Power Law for calculating Road User Cost (RUC), the Transport Research Laboratory (TRL) provided a variety of exponents for different mechanisms of degradation, as indicated in Table 2-3 (Arnold, 2017).

Table 2-3: Power-law exponents for different modes of deterioration

Mode of deterioration		**Range of exponents**
Flexible Pavements	Non-structural rutting	1.0 – 1.5
	Cracking	1.3 – 3.1
	Serviceability	4.4
	Rutting	4.0 – 9.6
	Asphalt fatigue	4 – 5
Rigid pavements	Rigid pavement cracking	5.5 – 18.0
	Faulting at joints	0.7
Subgrade	Deformation	4.0 – 7.4

Source: (Arnold, 2017)

The Fourth Power Law is a rule of thumb for comparing the amount of pavement damage produced by cars of varying weights in relation to axle loads. Equation 2-4 describes the Fourth Power Law.

$$\left(\frac{W_1}{W_2}\right)^4 \tag{2-4}$$

W1 is the weight of an axle on vehicle 1 in the equation, which we would compare to W2, the weight of an axle on vehicle 2 (Yiu, 2020).

Example: Consider a two-axle passenger automobile weighing 2 tonnes. If the weight distribution is considered to be even, each of the axles will carry 1 tonne. Consider a vehicle with eight axles and a weight of 40 tonnes; each axle would be capable of carrying 5 tonnes. The damage done by each axle of the passenger vehicle is 625 times the damage done by each axle of the truck, according to the Fourth Power Law calculation.

$$\left(\frac{5\ tonnes}{1\ tonne}\right)^4 = 625$$

Because the truck in this case has eight axles and the passenger vehicle only has two, the total pavement damage inflicted by the truck would be 625 x (8/2) or 2,500 times the passenger car.

The equation, however, has certain limits. Axles can theoretically be added to a vehicle to reduce the load borne by each axle. If the 40-tonne truck had 10 axles instead of 8, each axle would now carry 4 tonnes instead of 5, resulting in a comparative damage of:

$$\left(\frac{4\ tonnes}{1\ tonne}\right)^4 = 256$$

The proportional damage would still be smaller with the extra axles, 256 x (10/2) or 1,280 times the damage from the passenger vehicle. In truth, the relationship is rather complex. The installation of more axles increases the vehicle's weight, making it more damaging, especially on bridges, where the gross vehicle weight is the most important consideration (Yiu, 2020).). The level of pavement damage is affected by other factors such as vehicle speed, vehicle axle arrangement, and pavement design.

2.3.3 Effect of Overloading on the Service Life of a Pavement

Overloaded trucks reduce flexible pavement stress and rutting resistance. According to a study conducted by David Rys on flexible pavements using weigh-in-motion (WIM) data, when the percentage overloading rose by 20%, the fatigue life of asphalt pavement decreased by 50% (David Rys, Jozef Judycki & Piotr Jaskula, 2016). This leads to huge losses when pavements deteriorate prematurely. Overloaded traffic disorients the frequency of road asset maintenance and rehabilitation (Ojha, 2018). With minimal available resources, the transportation industry faces a risk if unplanned maintenance costs arise frequently. Even with firm enforcement of traffic loading regulations, overloading persists. It is therefore important for all the stakeholders involved in the transportation industry to come up with strategies that can help reduce the cases of overloading. An engineering recommendation that seeks to reduce the impact of overloaded vehicles on pavements is to design pavements that can bear overweight vehicles by modelling of pavement response (Jeongho Oh, E.G. Fernando & R.L Lytton, 2007). A study aiming to learn the relationship between the pavement life, base thickness, and the subgrade resilient moduli was conducted by Ahmed in 2012 (Ebrahim, 2012). Surface loads induced horizontal tensile strain at the bottom of the asphalt layer and vertical compressive strain at the top of the subgrade layer during pavement modelling (Ebrahim, 2012). Ahmed found out that increasing the axle loads had a direct effect on the compressive and tensile strains in the pavement layers while increasing the asphalt layer elastic modulus caused a decrease in the strains (Ebrahim, 2012). Excessive tensile strains cause cracking on the pavement layers while excessive compressive strain causes pavement deformation (Ebrahim, 2012). A conceptual response of pavement layers to load is depicted in Figure 2-2.

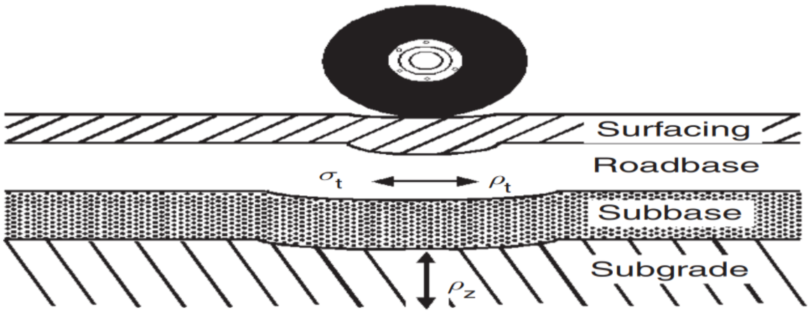


Figure 2-2: Conceptual response of pavement layers to load (O'Flaherty, 2007)

This excessive loading is usually observed from overloaded vehicles. Therefore for adequate design, Ahmed realised that the base thicknesses and the material resilient modulus were the key elements in controlling the extent of pavement distresses namely fatigue cracking and rutting (Ebrahim, 2012). In light of the above, adequate pavement design is therefore a crucial element in managing road deterioration due to overloading (Pengfei Liu & Dawei Wang, 2017). In a study conducted by Liu and Wang to model asphalt pavement response when subjected to heavy traffic loads, the contact pressure between the tire and the pavement increased as the axle load increased. As a result, the vertical compressive stress on the pavement models increased, creating rutting. (Pengfei Liu & Dawei Wang, 2017). The pavement models used had the properties shown in Table 2-4.

.

Table 2-4: Thicknesses and material properties of the model pavement layers (Pengfei Liu & Dawei Wang, 2017)

Layer	Thickness (mm)	Poisson ratio, µ	Elasticity Modulus, E (MPa)
Surface course	40	0.35	11150
Binder course	50	0.35	10435
Asphalt base course	110	0.35	6893
Gravel base course	150	0.49	157.8
Frost protection layer	570	0.49	125.7
Sub-grade	2000	0.49	98.9

The modelling results were graphically represented as shown in Figure 2-3 and Figure 2-4. The value of compressive stress decreases as the depth from the surface increases. The upper layers, such as the surface, binder course, and asphalt base course, are more heavily loaded than the lower levels. The compressive stress on the surface induced by the axle load of 20000 Kg (0.08MPa) was 1.1 times that caused by a conventional axle of 10000 Kg (0.07 Mpa) as shown in Figure 2-3. It was also shown that an axle load of 15000 kg created more compressive stress than a typical axle weighing 10000 kg. The compressive stress on the asphalt pavement structure is greatly increased as a result of this overload. Overloads cause the pavement components to degrade, resulting in the production of ruts and cracks on the pavement's surface.

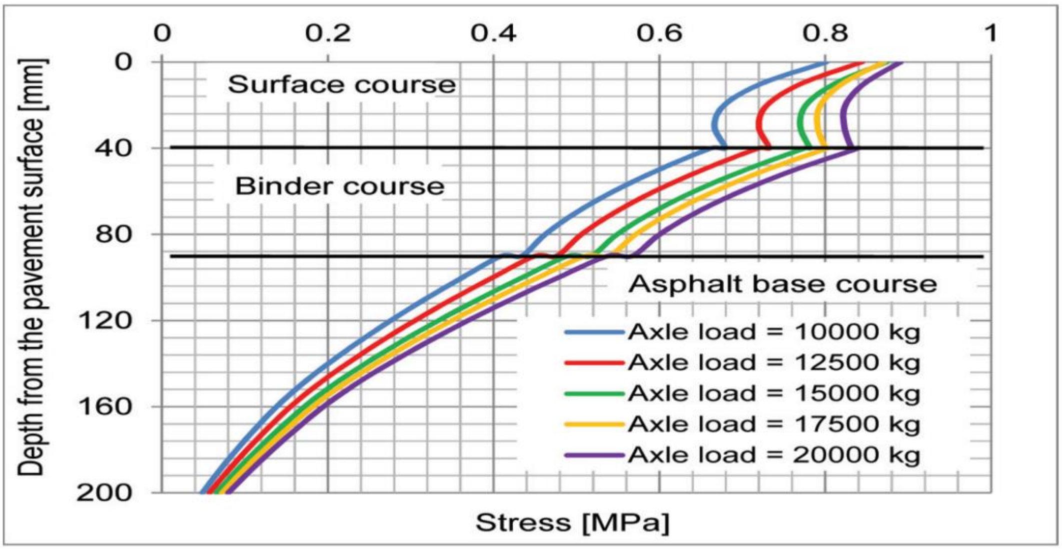


Figure 2-3: Depth from surface course to asphalt base course vs compressive stress (Pengfei Liu & Dawei Wang, 2017)

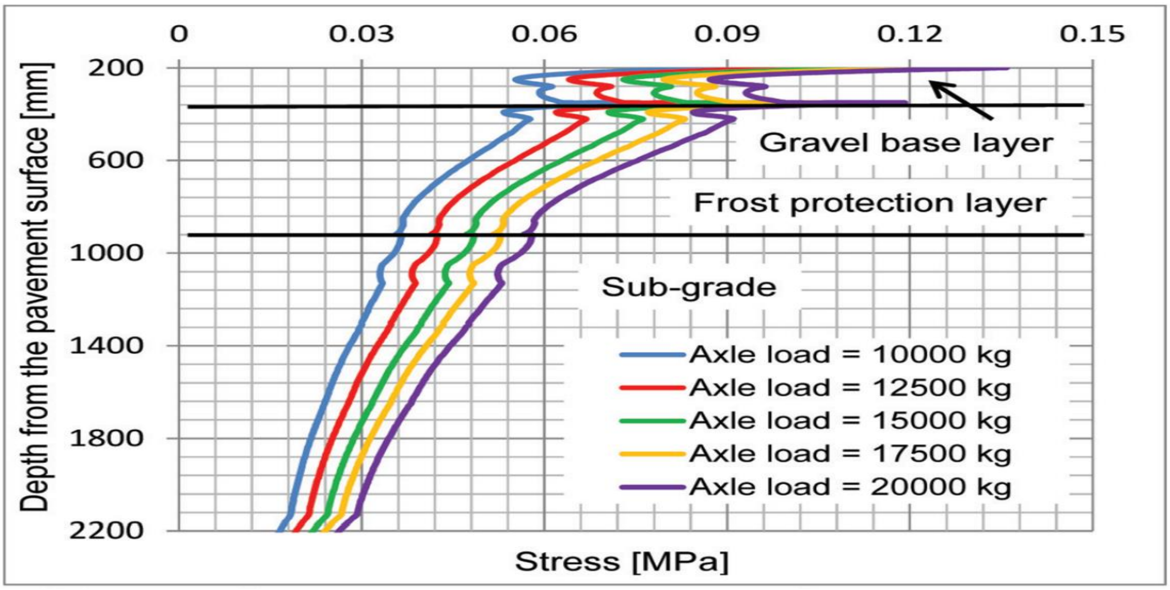


Figure 2-4: Depth from gravel base to subgrade vs compressive stress (Pengfei Liu & Dawei Wang, 2017)

Liu and Wang further investigated the effect that heavy volume traffic loads had on the tensile strain and the fatigue life of the model pavements. Fatigue cracking is a phenomenon observed on pavements where there is maximum horizontal tensile stress (Teklu, 2016). Liu and Wang found out that overloading caused an increase in the tensile strain and a decrease in the pavement's fatigue life by 48% as shown in Table 2-5.

Table 2-5: Relationship between axle load, tensile strain and fatigue life (Pengfei Liu & Dawei Wang, 2017)

Axle load (Kg)	Tensile strain (μm/m)	Fatigue life
10000	193	1.67e19 = 298,065,442.6
12500	224	8.86e18 = 581,747,326.6
15000	255	5.09e18 = 334,209,242.9
17500	279	3.51e18 = 230,466,491.7
20000	306	2.38e18 = 156,270,726.5

The material properties and the thicknesses of the asphalt pavement layer should be the key considerations while constructing pavements subject to heavy volume traffic. The fatigue and rutting resistance of a pavement can be improved using polyester and polypropylene fibre reinforcement (Teklu, 2016). When high modulus asphalt concrete is mixed with organic fibre, the shear stiffness and resistance to fatigue cracking improves (Teklu, 2016). Polymer modification is a brilliant way to improve the service life of a pavement. Pavements can be reinforced with geo-synthetic material like the stress-absorbing membrane interlayer (SAMI) to mitigate the effects of high volume traffic (Teklu, 2016). This in turn helps in prolonging the service life of the pavement by reducing its rate of deterioration. The SAMI is a high-performance product that is elastic and works collusively with a modified bitumen emulsion tack covered with chippings or pre-fabricated bitumen to form the stress-absorbing interlayer (Marcuzzi, 2022). The interlayer helps in distributing the strain and it delays any "bottom-up" destruction and cracking from the bottom layers of the pavement. Figure 2-5 illustrates the laying of SAMI on a pavement.

Figure 2-5: Laying of SAMI (Marcuzzi, 2022)

The design criteria for pavements subject to heavy volume traffic is that the surface should not undergo excessive deformation (Thom, 2014). Nick Thom, suggests that concrete is the ‘default solution’ because of its ability to resist excessive deformation (Thom, 2014). However, other treatments against cracking in asphalt pavements are available such as grid reinforcement. The grid reinforcement reduces the rate of crack propagation by ‘stitching’ the crack preventing the crack from opening at the location of the reinforcing strand (Thom, 2014). Figure 2-6 illustrates the ‘stitching’ effect of a grid reinforcement in an asphalt pavement layer. The rate of crack propagation increases in an unreinforced asphalt layer while it reduces in a reinforced asphalt layer.

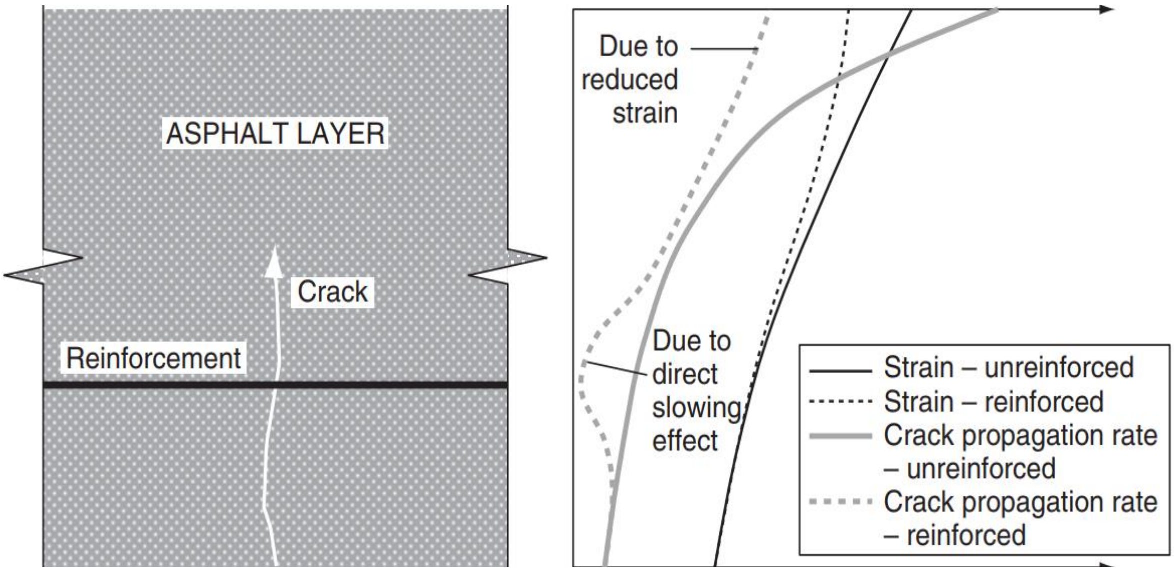


Figure 2-6: The effect of grid reinforcement (Thom, 2014)

This research has proven that overloading is still prominent along the section of the pavement in the area of study. Values such as the rate of overloading among various vehicle axle configurations and the values of overloads can be used to model pavements that will sustain these traffic loads. Jeongho, Lytton, and Fernando in 2007 studied the relationship between overweight trucks and the service life consumed and they realized that overweight trucks had an increased chance of pavement degredation (Jeongho Oh, E.G. Fernando & R.L Lytton, 2007). They studied trucks in pairs. The simultaneous passage of the overweight truck and legal truck over a modelled base and subgrade was used to determine the ratio of the service life consumed (Jeongho Oh, E.G. Fernando & R.L Lytton, 2007). The ratios were bigger than 1 which meant that the overloaded trucks reduced the pavements' service life to some extent. Some pavement distresses like crazing (formation of a network of fine cracks) and longitudinal cracks have been attributed to excessive loading as shown in Table 2-6 (Ministry of roads and public works, 1988).

Table 2-6: Typical defects affecting flexible pavements

Type of defect	Layer affected	Deterioration mechanisms	Causes
Longitudinal cracking	Asphalt concrete (AC) surfacing	Excessive and repeated loading	Insufficient thickness of AC Excessive deformation of the support
	Cement treated bases and asphalt concrete surfacing	Excessive and repeated loading	Insufficient thickness of the base Excessive deformation of subbase and subgrade
Crazing	Asphalt concrete surfacing	Excessive and repeated loading	Insufficient thickness of AC Advanced deformation of the support
	Cement treated bases and asphalt concrete surfacing	Excessive and repeated loading	Insufficient thickness of the base Excessive deformation of subbase and subgrade

Source: (Ministry of roads and public works, 1988)

The mandate of limiting the gross vehicle weight to allowable standards rests with KeNHA. By regulating the traffic loads, premature pavement failure can be prevented. Most countries have set limits due to the damages and losses caused by overloading. State authorities use permits as one of the most effective and frequent mechanisms for monitoring and regulating the operation of overloaded vehicles. (Imad Al-Qadi, Hao Wang & Junjie Qiu, 2017). Overloading has several negative impacts. Overloading reduces the vehicle's stability, makes it difficult to steer, and increases the stopping distance (Vosa, 2022). The relationship between the speed, gross vehicle weight, and the stopping distance of different truck types can be generated using Automated Dynamic Analysis of Mechanical Systems (ADAMS) software as shown in Figure 2-7 (Mohamed Rehan, Ahmed SaIfizul & Airul Sharizli, 2018). It is seen that when the gross vehicle weight is high then the stopping distance required is greater, especially for overloaded vehicles. Suppose the vehicles have the same gross vehicle weight, the vehicle with the higher number of axles will require less stopping distance because of superior vehicle dynamics.

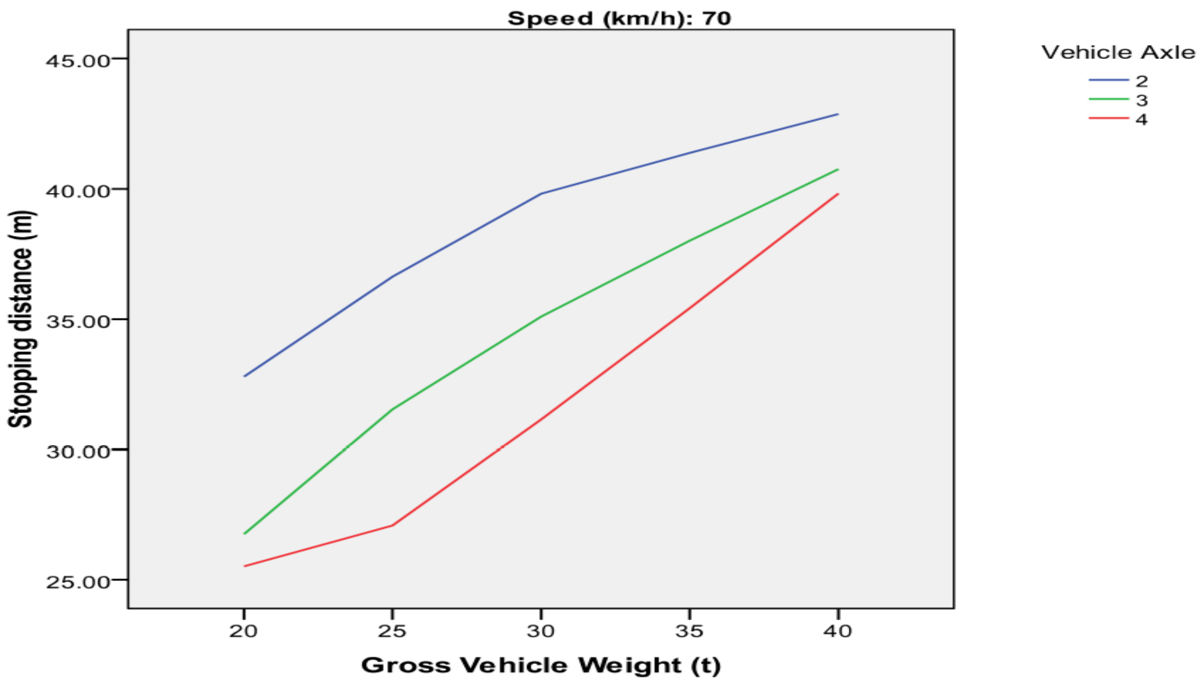


Figure 2-7: Effect of GVW on stopping distance for different truck types (Mohamed Rehan, Ahmed SaIfizul & Airul Sharizli, 2018)

Another way to illustrate the relationship between the number of axles, GVW, and the stopping distance is shown in Figure 2-8. Similarly, the greater the number of axles, the less the stopping distance required, and the heavier the truck the more the stopping distance.

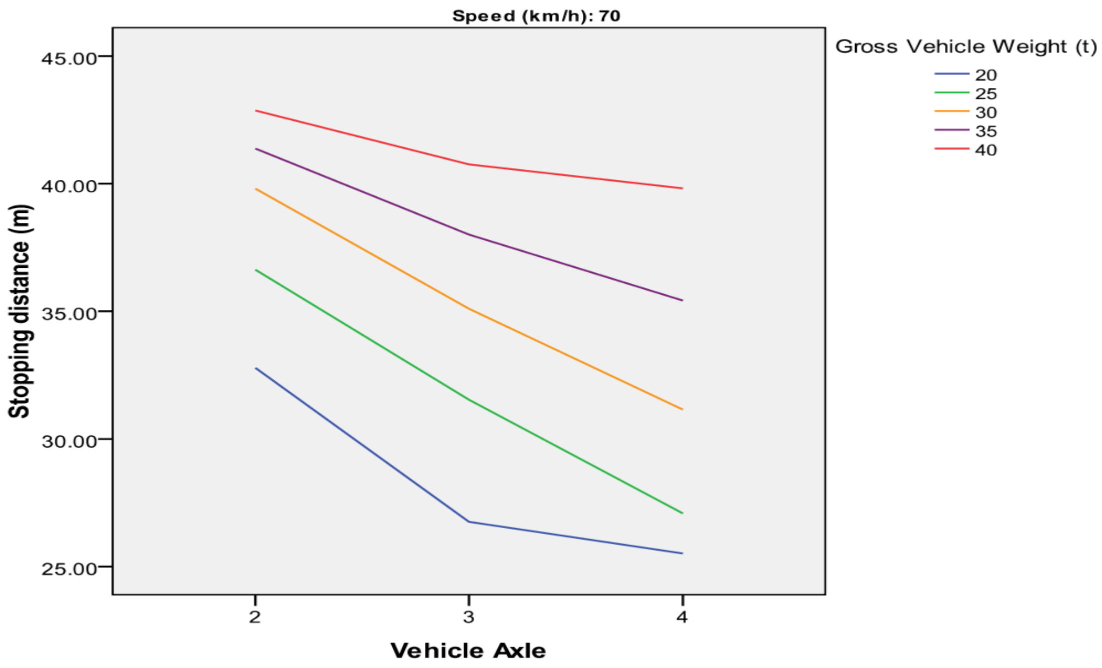


Figure 2-8: Effect of axle numbers on stopping distance (Mohamed Rehan, Ahmed SaIfizul & Airul Sharizli, 2018)

Overloading causes extensive strain on vehicle tyres. This may cause the tyres to overheat and tear and wear rapidly (Vosa, 2022). This makes vehicle maintenance expensive. Worn-out tyres also pose a great threat to road users as they reduce the grip of the tyres on the pavement which can cause skidding of the vehicle. Overloading makes insuring the vehicle null and void as it is illegal to overload hence when the vehicle is involved in a crash, its insurance may not cover the damages suffered (Vosa, 2022). Overloading is also an unfair means for rogue drivers to pocket extra cash from their delivery service (Brian Taylor & Norm Lindgren, 2000). Law-abiding drivers face unfair competition from indiscipline drivers with no regard to the traffic regulations. Overloaded vehicles have a higher fuel consumption rate (Vosa, 2022). This high consumption of fuel increases GHG emissions. This eventually leads to environmental degradation. Another downside to overloading is the lack of turbo power in overweight vehicles on uphill slopes (Mohamed Rehan, Ahmed SaIfizul & Airul Sharizli, 2018). This may eventually lead to slow-moving traffic and the lack of enough stopping distance which results in braking problems. Overloaded vehicles also over speed on downhill slopes. Overweight vehicles take too long to overtake and this poses a risk to other drivers (Mohamed Rehan, Ahmed SaIfizul & Airul Sharizli, 2018). Overloading puts a financial burden on road users as they will have to incur unpremeditated maintenance and rehabilitation costs. A study on the impact of overloading on pavement models done by Pais, Amorim, and Minhoto revealed that overloading can increase the cost of pavements by 100% compared to vehicles within the allowable load limits (J Pais, R Amorim & C Minhoto, 2013). Drivers operating heavy goods vehicles are prone to driver fatigue associated with long-distance travel. They pose a threat to other road users as they are less alert thereby compromising road safety (Mohamed Rehan, Ahmed SaIfizul & Airul Sharizli, 2018).

In Nepal, Nath Ojha also conducted a study about the consequences of overloading on the pavement service life. He realised that the service life of the lane carrying overweight vehicles (Narayanghat – Mugling direction) might be reduced by 59.9% which was not the case for the lane in the other direction (Mugling – Narayanghat direction) which had no overweight vehicles (Ojha, 2018). The vehicle damaging factors for the vehicles in the overloaded lane were greater than those in the other lane which hints at a greater consumption of pavement service life (Ojha, 2018). The load-road life relation of the pavements studied by Nath is illustrated in Figure 2-9. From the ESAL tabulations, the standard traffic load of Narayanghat – Mugling direction in 10 years is 34.2 million ESAL, but this number is reached in 4.1 years in the overloaded condition (by interpolation). This means that the service life of the overloaded lane is reduced by 5.99 years. These overloads may eventually lead to premature pavement failure if no appropriate measures to curb overloading are taken.

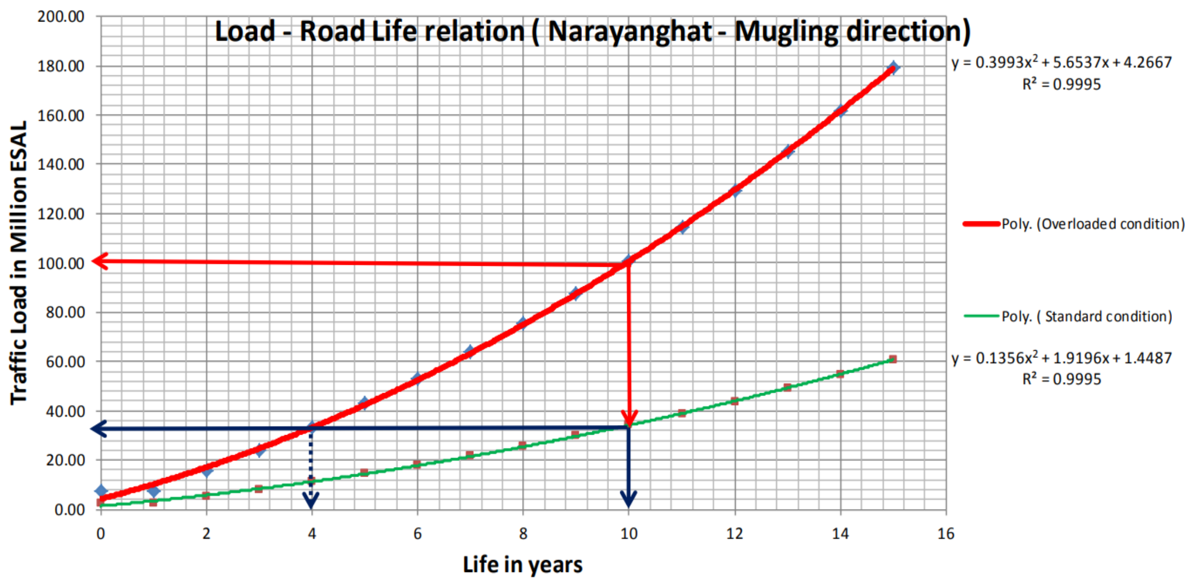


Figure 2-9: Load-road life relation for the lane with overloads (Ojha, 2018)

In 2018, Muhammad and Rawid attempted to estimate the number of overloaded cars and their impact on road pavement using ESAL, which is often used as a significant input for estimating pavement thickness during road design (Muhammad R & Rawid K, 2018). Their analysis found that the axle design had a considerable impact on the pavement. They discovered that 2-axle cars had a vehicle factor almost 3.33 times that of 3-axle vehicles and 5.45 times that of 6-axle semi-trailers (Muhammad R & Rawid K, 2018).). Furthermore, they discovered that a twofold increase in the asphalt layer lowered the vehicle factor by 47 percent. In view of the foregoing, government entities are advised to encourage the usage of semi-trailers (Muhammad R & Rawid K, 2018). The vehicle configuration used by Muhammad and Rawid is shown in Figure 2-10.

Table 1. Vehicle classes and allowed maximum load

Class of vehicle	Maximum load per Axle (kN)					
	1st axle	2nd axle	3rd axle	4th axle	5th axle	6th axle
B2	53.94	117.68	-	-	-	-
BH3	53.94	107.87	107.87	-	-	-
S123	53.94	107.87	107.87	101.33	101.33	101.33
S113	53.94	117.68	101.33	101.33	101.33	-
S112	53.94	117.68	107.87	107.87	-	-

Figure 2-10: Vehicle classes and allowed maximum load

The variation of vehicle factor in terms of ESAL with the thickness of the asphalt layer was graphically presented by Muhammad and Rawid as shown in Figure 2-11. When the asphalt layer thickness was raised from 10 cm to 20 cm, Muhammad discovered that the vehicle factor decreased by around 45-47 percent.

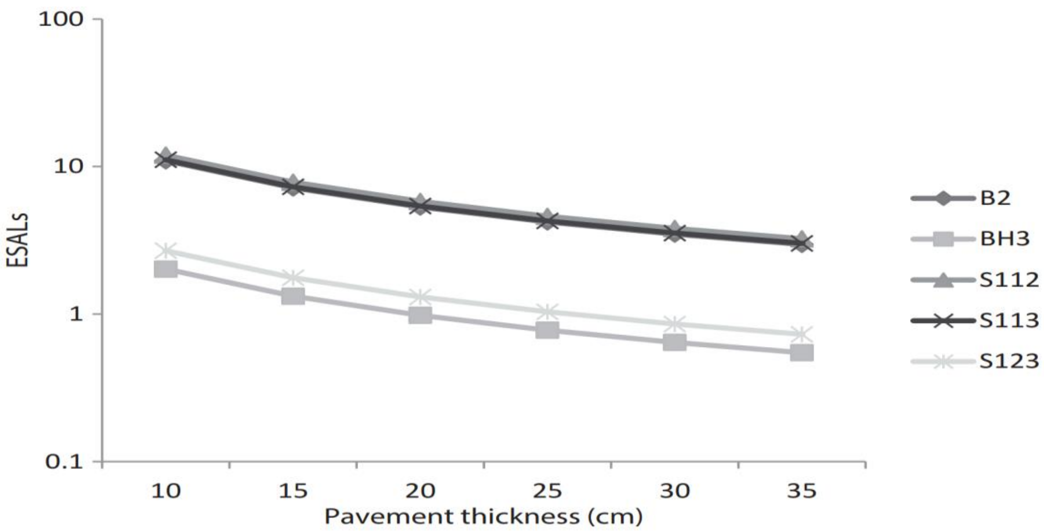


Figure 2-11: Variation of ESAL and asphalt layer thickness

The technological advancement in the transportation industry such as the use of Weigh in Motion (WIM) systems has greatly helped in controlling the level of overloaded vehicles (David Rys & Piotr Jaskula, 2018). KeNHA has installed a virtual weighbridge along the pavement in the area of study.

It has also a mobile weighbridge unit that works collusively with the static weighbridge in regulating and monitoring axle loading of the vehicles in the area of study. Accurate and advanced technology enhances the efficiency of traffic monitoring. This research has depicted the firm enforcement of the traffic regulations and axle load limits by KeNHA. However, to optimize the service life of the pavement, efforts to increase the efficiency in pavement management have to be made.

The estimated pavement damage cost varied greatly based on the volume of traffic and the kind of pavement, according to another research conducted by the Illinois Center for Transportation in Illinois (Imad Al-Qadi, Hao Wang & Junjie Qiu, 2017). Adams claims that the serious consequences of overloaded cars are not adequately represented in Illinois' current permit costs and procedures (Imad Al-Qadi, Hao Wang & Junjie Qiu, 2017). This has sparked studies into the impact of heavy automobiles on pavements in different countries. To compensate for the increased cost of damage while facilitating commerce and the movement of goods and services, several governments offer special overweight permits (Imad Al-Qadi, Hao Wang & Junjie Qiu, 2017).

The Montana Department of Transportation used data from a network of WIM sensors to program weight enforcement activities of monitoring personnel. They purposed to determine whether mitigating the destruction of infrastructure by overloaded vehicles would be more efficient using WIM data (Jerry S & Jodi C, 2003). During the baseline year, they tabulated data from the various WIM centres within Montana and accessed the damage caused by overloaded vehicles.

The trends identified in the baseline year were used to direct patrol enforcement (Jerry S & Jodi C, 2003). The patrol officers were directed to the specific vehicle configurations popular for overloading as well as their time of operation and direction of travel. In the subsequent year of the operation, pavement destruction from overloaded vehicles was reduced by 4.8 million ESAL, and also a reduction in the number of overloads by 20% across all enforcement stations was achieved (Jerry S & Jodi C, 2003). Even though the operation was a success in the subsequent year, its success was uncertain in the long term run (Jerry S & Jodi C, 2003).

The use of variable tyre pressure to reduce the strain on the flexible pavement is an example of innovation in transportation technology. On pavement models, Owende and Hartman tested the possible irritation created by a 3-axle truck's single steering wheel and rear twin wheels in tandem (Philip O & Anton H, 2001). The pavement models used had thin asphalt layers and soft soil. Four tyre inflation pressures (350, 490, 630. 770 KPa) and three sets of tuck wheel loads were used in the experiment.

The lateral strain induced by a single steering wheel was shown to be the most important factor in fatigue failure in the experiment (Philip O & Anton H, 2001). The amount of strain is determined by the axle design, the asphalt layer's composition, and the truck's speed. In addition, Owende and Hartman found that lower tyre pressures extended the surface layer's fatigue life by 200% for the rear dual wheels and 300% with regards to the steering wheel (Philip O & Anton H, 2001). Some vehicles like haulage trucks which have mechanisms such as the central tyre inflation that vary tyre pressure can help improve the serviceability of pavements overlying soft soil foundations.

With dwindling budgets for road rehabilitation and deteriorating road infrastructure, the sound courses of action to amplify the service life of our roads would be to enforce gross vehicle weight (GVW) and axle load controls on the existing road infrastructure. Conventionally, premature pavement deterioration has been quantified per research conducted at the AASHO Road Test (Jacob, 2020). The test measures damage from overloaded vehicles in terms of equivalent single axle loads (ESALs), using the 'fourth power rule,' which was created in the late 1950s to estimate overload damage (Jacob, 2020).

The primary data needed for the estimation of the effects of overloading are the axle loading of various vehicles, traffic vehicular data including the GVW of all vehicle classes. The secondary data needed for the estimation includes the pavement design life and the traffic growth rate. These data are used to predict the Remaining Service Life of a pavement (Jacob, 2020).A Vehicle Damaging Factor (VDF) is a factor used to assess the extent of pavement destruction caused by a vehicle. Countries have standard values of VDF for various vehicles that drivers need to adhere to so as to prevent premature pavement deterioration. The factor is given by the equation 2-5.

$$VDF = k\left(\frac{Q_i}{Q_s}\right)^4 \qquad (2\text{-}5)$$

Where Q_i is the actual load, Q_s is the standard axle load 80 kN, k is 1 for single axle load, k is 0.086 for tandem and 0.053 for tridem axle (Jacob, 2020).

The Cumulative Equivalent Single-Axle Loads which is the total number of traffic during the service life is estimated by using the equation 2-6.

$$W_{18} = \sum_{j=1}^{n} N_j \times VDF_j \times D_D \times D_L \times 365 \quad (2\text{-}6)$$

Where W_{18} is design traffic in the design life of the pavement. N_j denotes the vehicle count for a particular axle configuration per day, D_D and D_L are the distribution factor for direction and lanes (Jacob, 2020).

VDF data and the proportion of overloaded trucks from WIM survey analysis are used to determine the CESAL (Cumulative Equivalent Single Axle Loads) and the number of design traffic to analyze the impact of overloaded trucks on design life. Automatic traffic counters or human in-field counts are used to collect daily traffic statistics. To assess the impact of overloaded vehicles, the CESAL result (Overloaded CESAL) is compared to CESAL estimation using standard load (Standard CESAL) (Jacob, 2020). The pavement's service life decrease value may then be computed.

The remaining service life of the road may be examined to measure the impact of overloaded cars on pavement structure. The assessment of the total years that a pavement will remain functionally and structurally in a normal state with merely regular preservation is known as the Remaining Service Life (RSL) of a pavement (Jacob, 2020) . The RSL is calculated using equation 2-7.

$$RSL = \frac{CESAL_{Standard}}{CESAL_{Overloaded}} \times Design\ life \quad (2\text{-}7)$$

Where: RSL is the remaining service of pavement (years) while the design life of pavements in most cases is 15 years.Suppose an axle load survey and traffic count surveys yield the following vehicle damaging factors in Table 2-7 and Table 2-8 below and assuming a value of 0.5 as the distribution factor for direction and lanes, the RSL can be determined.

Table 2-7: Estimated traffic in the design life of pavement (standard)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
Two axle	110	3.898	0.5	0.5	365	241515
Three axle	79	3.679	0.5	0.5	365	40189
Four axle	407	5.934	0.5	0.5	365	278629
Five axle	120	6.222	0.5	0.5	365	102845
Six axle	147	6.003	0.5	0.5	365	219501
Total						434682

Table 2-8: Estimated design traffic in the design life of pavement (overloaded)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
Two axle	679	1.925	0.5	0.5	365	119305
Three axle	120	4.464	0.5	0.5	365	48769
Four axle	515	9.009	0.5	0.5	365	423023
Five axle	181	8.210	0.5	0.5	365	135709
Six axle	401	19.56	0.5	0.5	365	715116
Total						1441923

$$RSL = \frac{434682}{1441923} \times 15 = 4.52\ (4\ years\ and\ 6\ months)$$

Applying the equation, the RSL of pavement, in this case, is 4.52 years. Conclusively, there is a reduction in the service life of the pavement by 10.48 years from its design life which is 15 years. This means that premature deterioration of the pavement will begin just after four years and six months from when the pavement is opened to traffic.

2.4 Pavement failure

2.4.1 Factors that Cause Pavement Failure

i. Overloading. The design axle load of the Northern Corridor was 80kN but there have been numerous cases of overloading by trucks transporting goods to and from the port of Mombasa. The government has come up with measures to curb overloading such as introducing weighbridges at designated points along the corridor and imposing fines to those who are found overloading (David Rys & Piotr Jaskula, 2018).

ii. Extreme weather conditions including high temperatures as the road traverses an arid area of Eastern Kenya into the Coastal region where the temperatures are very high which leads to cracking and bleeding (Thom, 2014).
iii. Poor shoulder protection at some sections on the road has led to edge failures (Ministry of Transport and Communication, 1987).
iv. Use of clayey soils (Babu, 2016) in preparation of the subgrade during construction resulting in base failures due to inability to support heavy axle loads.
v. Poor drainage conditions allowing rainwater to infiltrate into the pavement during the rainy season. This phenomenon has become more critical as the asphalt concrete has been detached from the underlying layers leading to pavement failure (Ministry of Roads and Public Works, 1988).

2.5 Weighbridges

The Kenya National Highways Authority has installed Static Weighbridge Systems at Mariakani, Athi River (Plate 2-2) and a virtual weighbridge on the southern bypass along the Northern Corridor (KeNHA, 2021). There are other subsidiary weighbridges and private weighbridge service providers along the route who offer the weighbridge services to vehicles before the reach of designated weighbridges installed by KeNHA including the Mtwapa Weighbridge station along route B8 (KeNHA, 2021).

The Virtual Weighbridge System uses the High-Speed Weigh-in-Motion (WIM) technology by the use of Kistler Quartz Sensors, the Integrated MPLS Connectivity (Jerry S & Jodi C, 2003) that gives real ICT network coverage to a control centre located at Mlolongo that operates on a 24-hour basis and has advanced analytical capabilities. The WIM weighbridges have other advanced features such as the Automatic Number Plate Recognition (ANPR), overview camera that documents vehicles that violate the rules and three staggered half-width sensors (Jerry S & Jodi C, 2003).

Plate 2-2: Oil Tanker at the Mlolongo Weighbridge Station in Athi River

Source: (The Northern Corridor Transit and Transport Coordination Authority, 2020)

2.5.1 Working Principles of the Virtual Weighbridge (VWB)

The VWB works on a WIM platform that captures data from cameras and sensors installed in place and uses the data to classify the respective vehicle and then transmits the data to the database at the control centre for analysis (Jerry S & Jodi C, 2003). The Control Centre at Mlolongo in Athi River is equipped with processing units that analyses and stores the information which can be accessed from the web and by the KeNHA enforcement unit officers. The system allows people in charge to use the data for enforcement purposes as the system has a distributed capability that transmits live data.

The VWB system is important in that it reduces cases of overloading vehicles that end up damaging roads, bridges and pavements and poses risks to other road users (KeNHA, 2021). Overloading also gives the vehicle operators an unfair tax-paying advantage over other compliant road users and the VWB system helps in identifying the overloaded vehicles for punitive measures to be taken (J Pais, R Amorim & C Minhoto, 2013).

The VWB system provides historical data to KeNHA that is necessary for Axle Load Control decisions and provides data for the prosecution of axle load limit violators. The system also provides the necessary information about road lanes and the measurement of wheel tracks for estimating sensor surface wear and road ruts (Jerry S & Jodi C, 2003). Besides, the VWB system also provides real-time traffic data that is essential for the road planning process. Therefore, there is no doubt the combination of the VWB system and other technologies such as the Automatic Number Plate Recognition and analysis systems at the control centre plays an important role in reducing the illegal overloading of vehicles (Jerry S & Jodi C, 2003). The ability to control overloading vehicles increases the life span of road pavements and eliminates costs associated with premature maintenance and repair of roads, allowing the road authorities such as KeNHA and the Kenya Roads Board to allocate the resources to other more beneficial uses. The VWB systems also make roads safer by identifying violators who may cause danger to other road users.

2.6 Axle Load Control

Due to the increased number of trucks that use the Northern Corridor transporting goods from the port of Mombasa to the entire East and Central Africa region, there is increased loading on the road and to maintain the state of the road, the trucks must pass via weighbridges to ensure that axle load limitations are met (NCTTCA, 2021).

2.6.1 The KeNHA Mandate on Axle Load Control

KeNHA is mandated by the constitution of Kenya to oversee the construction and maintenance of national highways such as the Northern Corridor and under the mandate, it is supposed to perform the following functions;

i. Advise the road users on the legal requirements regarding vehicle axle load limits and dimensions.
ii. Provide evidence necessary for the prosecution of axle load limit offenders.
iii. Ensure that road users adhere to set rules and regulations regarding axle load limits as stipulated by the laws of Kenya (KeNHA, 2021).

2.6.2 Axle Load Limits and Fines

To facilitate the movement of cargo on the Northern Corridor from the port of Mombasa countrywide, KeNHA, following a proposal by the minister for transport and infrastructure to amend the traffic act has enforced maximum allowable weight limits to curb the cases of overloading that lead to deterioration of the roads (KeNHA, 2021).

Goods vehicles are subject to the Kenyan Gross Vehicle Weight limits. A tolerance of 5% of the GVW limit is permitted but a vehicle loaded beyond this weight is deemed to be in breach of the traffic laws.

2.6.3 Minimum Fines for Overloading

KeNHA has set up an axle load control department mandated to prosecute overloading cases based on the Traffic Act, impose fines for excess axle load based on the weights and measures act. The fines for overloading to discourage freighters from overloading are as tabulated in Table 2-9 below (KeNHA, 2021). The offenders are charged a double amount on a second conviction as compared to the amount charged on the first conviction. This is to discourage notorious transporters who may take advantage of the small amount charged on the first conviction to continue repeating overloading knowing they will pay the fine provided the required amount of cargo is transported at once.

Table 2-9: Minimum Fines for Overloading (1 USD = 108.60 Ksh)

Degree of Each Axle Overloading or Excess Gross Vehicle Weight in Kilograms	**Minimum Fines (KSh)**	
	Fine on First Conviction	**Fine on Second or Subsequent Conviction**
Less than 1,000 kg	KSh 5,000	KSh 10,000
1,000 kg or more but less than 2,000 kg	KSh 10,000	KSh 20,000
2,000 kg or more but less than 3,000 kg	KSh 15,000	KSh 30,000
3,000 kg or more but less than 4,000 kg	KSh 20,000	KSh 40,000
4,000 kg or more but less than 5,000 kg	KSh 30,000	KSh 60,000
5,000 kg or more but less than 6,000 kg	KSh 50,000	KSh 100,000
6,000 kg or more but less than 7,000 kg	KSh 75,000	KSh 150,000
7,000 kg or more but less than 8,000 kg	KSh 100,000	KSh 200,000
8,000 kg or more but less than 9,000 kg	KSh 150,000	KSh 300,000
9,000 kg or more but less than 10,000 kg	KSh 175,000	KSh 350,000

Source: (KeNHA, 2021)

The exchange rate quoted obtained on 2nd Aug 2021

2.7 Pavement Maintenance

The Computerized Information Maintenance Management Systems is a program used by road authorities in Kenya such as KeNHA and KRB to manage Kenyan roads, bridges and pavements (JICA, 2017). The Road Maintenance Information System is used in monitoring road conditions and managing road maintenance works. On the other hand, the Pavement Management Information System is used for short term and long-term planning of rehabilitation and pavement resurfacing works on major roads in Kenya (KeNHA, 2021).

Vision 2030 is Kenya's long-term development plan through the Kenyan government that has focused on transforming the economy of the country to a middle-income economy come 2030 (Vision delivery secreteriat, 2019). To achieve this goal, modern and efficient infrastructure facilities such as well-maintained roads are necessary. This calls for the rehabilitation and upgrading of the standards of roads to improve the transportation system and enable faster movement of commodities. The Northern Corridor is a major trunk road that connects the port of Mombasa to the entire East and Central Africa region that it serves. The road is an important asset to the growth of the economy of Kenya and those of the neighbouring countries that rely on the port of Mombasa for the importation of their goods (NCTTCA, 2021). The government of Kenya has made several steps in maintaining the Northern Corridor in a good status to facilitate the transportation of goods from the port of Mombasa to various destinations. According to the World Bank's March 2010 Country Partnership Strategy, improvement of infrastructure helps in eradicating poverty and eventually improves the economy of a country (The World Bank, 2011).

There have been significant policy formulations and institutional reforms in the public transport sector over the past few years. The road authorities in Kenya such as KURA, KeRRA, KeNHA and KRB with the assistance of the International Development Association (IDA) have formulated policies and executed several programs focused on maintaining road assets in Kenya (Kenya roads board, 2022). The Road Maintenance Levy Fund (RMLF) is managed by the Kenya Roads Board which allocates the funds to the road maintenance agencies such as KeNHA to carry out maintenance of road assets in Kenya. The policies and reforms have brought about improvements in the status of roads across Kenya, for instance, the Northern Corridor (Kenya roads board, 2022).

2.7.1 Importance of Pavement Maintenance

The goal of pavement maintenance is to preserve the road asset and should be done regularly (Nicholas & Lester, 2009). Pavement maintenance comprises activities to keep the pavement and other road facilities in the initial as-built condition. Maintenance of pavements involves minor improvements and repair of defects to avoid excessive deterioration of the status of road that will lead to increased maintenance costs (Ministry of Roads and Public Works, 1988). Road maintenance is a scheduled and budgeted activity and therefore maintenance as a result of overloading might lead to impromptu excessive spending. This money can be saved and channelled to other government projects if the root cause of overloading is dealt with and drivers trained on vehicle loading limits and various charges upon overloading.

2.7.2 Pavement Maintenance Works on the Northern Corridor

The World Bank under the Kenya Transport Sector Support Project (KTSSP) has remitted funds for the improvement and upgrading of Kenyan roads. Under the program, the World Bank has approved over Ksh 24 billion for maintenance and repair of major sections of the Northern Corridor (The World Bank, 2011). The maintenance works include the addition of another bitumen layer to some sections of the road, expansions of shoulders, improving drainage facilities, realignment of some sections of the road passing through townships, and construction of bus stops and parking bays in areas such as Samburu and Mackinnon road towns. The Road Maintenance Fuel Levy Fund and the World Bank funds are used in funding the maintenance works (Kenya roads board, 2022).The Northern Corridor undergoes regular maintenance works as seen in Plate 2-3.

Plate 2-3: Section of the Northern Corridor under Maintenance

Source: (The Northern Corridor Transit and Transport Coordination Authority, 2020)

As required by the Kenya Roads Board (KRB) Act 1999, the Kenya National Highways Authority (KeNHA) carries out an Annual Road Inventory and Condition Survey (ARICS), an inventory of roads and their condition (Kenya roads board, 2022). The inventory captures the length of the road, drainage structures on/along the road, road furniture, services on/across the road, the extent of road reserve and any other issues that may affect the functioning of the highway (Kenya roads board, 2022).

The condition of the road is measured in terms of its roughness on how comfortable motorists drive on the road. Roughness is assessed by the International Roughness Number (IR), which quantifies the vibrations felt by a moving vehicle's tyre (Ministry of Transport and Communication, 1987). The lower the IR value, the more pleasant the journey. A rutted road represents the signs of an issue that has to be investigated further. The Annual Road Inventory and Condition Survey (ARICS) is conducted once a year with the use of specialized equipment that can detect vibrations and convert the data into infrared. ARICS is carried out by KeNHA using a unique machine created in collaboration with JICA and mounted to a vehicle to record vibrations (Kenya roads board, 2022).

2.7.3 Purpose of Annual Road Inventory and Condition Survey (ARICS)

ARICS is carried out to obtain data that is used for the following amongst others (Kenya roads board, 2022):

i. Interventions required yearly or periodically to maintain the road asset
ii. Priority allocation of funds based on availability and conditions of the various road sections
iii. Preparation of Annual Work plans as required by Kenya Roads Board in the utilization of Road Maintenance Levy Fund (RMLF)
iv. Predicting a trend in the deterioration of the road and timely do required interventions to maintain the road asset.
v. Utilization for future plans of the road network

ARICS of 2021 was carried out from March to April 2021. The total KeNHA network is approximately 21,414 km as compared to 17,949 km in ARICS 2020. The increase in the network is attributed to the additional network allocated to KeNHA in October 2020 (Kenya roads board, 2022).

2.8 Pavement Maintenance Costs

Pavement maintenance costs vary according to the road conditions, geographic location of the road, traffic volume, climatic conditions, and the technical equipment required, the work methods to be involved among other factors (Ministry of Roads and Public Works, 1988). In the beginning, the cost calculations need not be precise in cases where the maintenance program is not in place or cases where unplanned maintenance occurs due to unforeseen road deterioration due to overloaded axles. However, when the calculations of road maintenance require the use of advanced road management systems or overwhelming formulas, precision is key (Kenya roads board, 2022). A road management program enables accurate estimation of maintenance costs by allowing direct and indirect assessments to be conducted on the road before maintenance works can begin. In Kenya, the road agencies such as KeNHA use competent road maintenance management programs and monitoring systems for major trunk roads such as the Northern Corridor and have transparent procurement procedures for allocating maintenance tenders to private companies (KeNHA, 2021).

For the financial year 2020/2021, KeNHA budgeted a total of Ksh. 152,648,389 for the rehabilitation of a 26km strip of the A8 Northern Corridor stretching from Museum Hill to Athi River covering the section under study. Conclusively, pavement rehabilitation and upgrade is a costly venture in that it is labour intensive and requires expensive resources like intricate pavement evaluation machines. The rehabilitation parameters of the 26km stretch are summarized in Table 2-10 below.

Table 2-10: Maintenance costs for the section of the (A8) Northern Corridor stretching from Museum Hill to Athi River

Period	2017 - 2021	2021 - 2023
Road Code	A8	A8
Road Length (KM)	26	26
Budget	295,169,212.88	396,112,146.30

The road A8 is subject to heavy traffic as a significant amount of heavy good vehicles traverses the route. This heavy traffic causes pavement deterioration and hence the need for regular maintenance. Lorries that are overloaded beyond their GVW limit are less able to stop quickly in emergencies leading to accidents. These accidents are costly in that the road and adjacent road furniture gets damaged in accidents. Oil spills weaken the bituminous surface of the roads leading to premature maintenance works. The huge amounts spent on pavement maintenance would be better utilised for additional pavement construction or in other sectors.

Generally, the pavement condition of the Northern corridor at the Athi River interchange is good. This is attributed to the high-level maintenance conducted by the road authorities periodically. The pavement, therefore, serves its purpose to a great extent**.**

2.9 Literature Review Summary and Research Gap

Overloading has been a serious menace in the transport industry around the area of study. There is need to involve transporters about the functionality of static, virtual and mobile weighbridges and acceptable load limits of various trucks. Truck manufactures need to be brought on board so that the trucks are manufactured in such a way that the load is distributed to all axles and not just concentrated on one axle/tandem axle, on the other hand, the government need to make sure that the mobile weighbridge operators are distributed in most feeder roads so that loaded trucks cannot evade the weighbridges. Regulating traffic loading on our roads and quantitative estimation of the impact of overloading on pavement life need to be given special attention as it causes the governments so much loses in terms of unplanned maintenance works on the roads.

The first objective of the Northern Corridor Transit and Transport Agreement was to create a Sustainable transport system, which in return would economically help in promoting efficient and competitive transport in terms of cost. It’s on the above basis of traffic load regulation that this study on traffic loading trends was carried out on a section of the Northern Corridor traversing the region to analyse the causes of overloading, its effects to the life span of our roads, come up with measures to curb it out completely so that the resources spent on unplanned road maintenance caused by overloading can be redirected to other development activities.

Literature from the Kenya Roads Board, the Kenya National Highways Authority and the Ministry of Roads and Public Works was reviewed. The literature reviewed covers previous research done by road agencies in Kenya including the Kenya Roads Board, the Kenya National Highways Authority and the Ministry of Roads and Public Works. Several aspects related to this study have been reviewed and is what the study was expanded from. A study by the Ministry of Roads and Public Works (1988) on axle load distribution on the section of the Northern Corridor between Mombasa and Nairobi was reviewed and from the study, it was seen that 25%-50% of axles in the Mombasa-Nairobi direction and 5%-22% of axles in the Nairobi-Mombasa direction were overloaded which shows a high rate of traffic overload causing major deterioration on the Northern Corridor and in particular to the section that was studied.

Literature on the Vehicle weight to road damage levels was also reviewed and was used to establish the levels of pavement deterioration expected for a certain level of load using the fourth power law. A study reviewing the fourth power law by TRL shows that the fourth power law can have various exponents depending on the type of pavement deterioration being investigated. The law can be used to predict the remaining pavement service life. To extend the service life of the pavement, proper maintenance and operational practices are recommended. These include axle load control as overloading is a major cause of road deterioration and timely pavement rehabilitation and maintenance to control premature deterioration. Axle load control can be done using Weigh in motion systems that are located at weighbridges. Static and mobile weighbridges can also be used to enforce axle load limits.

Other aspects that were crucial for this study included the Vehicle Axle Loads, Vehicle Equivalent Factors and aspects leading to pavement failure along the Northern Corridor.

Furthermore, literature on pavement design and traffic records on the Northern Corridor has been reviewed and this information assisted in the collection of data for the study and brought about a better understanding of the effect of overloading on the Northern Corridor.

Previous and recent studies have clearly illustrated the negative impacts of overloaded vehicles. Overloading has been cited as a major cause of premature pavement deterioration. An overload increment of 20% is capable of reducing the fatigue resistance of a pavement by 50% according to a study done by David in 2016 (David Rys, Jozef Judycki & Piotr Jaskula, 2016). Furthermore, overloading causes an increase in the tensile and compressive strain in the pavement layers which leads to fatigue cracking and excessive deformation respectively. Overweight vehicles have also been found to immensely reduce road safety. Overweight vehicles have limited manoeuvrability. They are too slow on uphill slopes and too fast on downhill slopes due to reduced braking ability. They also take too long to overtake which poses a threat to other drivers. Driver fatigue is also a common phenomenon among drivers who operate heavy good vehicles. When fatigued, the drivers become less alert and are prone to causing road accidents. Rogue drivers who overload their vehicles pocket extra profit unfairly compared to law-abiding drivers resulting in unfair competition. Additionally, overloaded vehicles increase maintenance costs. A study conducted by Pais and Amorim in 2013 revealed that overloaded vehicles can increase the pavement expenditure by more than 100% compared to vehicles within the legal load limits (J Pais, R Amorim & C Minhoto, 2013). Overloaded vehicles also have higher fuel consumption rates which lead to increased GHG emissions. Overall, overloading has very detrimental effects and can cause a serious lag in the transportation industry. Nonetheless, technological development can help combat the overloading menace. The use of WIM systems has helped in the efficient monitoring of vehicle loads across the globe. This can help reduce the rate of pavement deterioration significantly. Adequate pavement design using modern construction techniques such as reinforcing asphalt with organic fibre also has helped to increase the bearing capacity of pavements (Thom, 2014). The use of polymer modifiers such as SAMI has helped to improve the rutting and fatigue resistance of pavements (Vosa, 2022). The use of technology such as ADAMS has enabled the modelling of pavement response to loads. The modelling can help to predict the behaviour of pavements under different loading and design for more efficient pavements. The use of variable pressure tyre systems in trucks has also been found to minimise the distress on asphalt pavements.

This research has quantified the impact of overloading on the pavement service life of the Northern corridor Athi River – City Cabanas highway section in Kenya. The predictions of the remaining service life can be used to schedule timely maintenance and rehabilitation activities This research has also identified the vehicle loading trends along the corridor in the area of study. The trends can help to programme and schedule enforcement activities to efficiently deal with overloading. This research has also identified the most critical axle configuration with regards to the vehicle damaging factors. Such information can be used to choose the most appropriate freight vehicles that cause the least pavement damage. Moreover, this research has attempted to understand the relationship between road user characteristics, traffic and road asset management policies, and overloading. This has helped to identify the reasons for continued overloading despite there being measures to curb overloading.

This study helps in understanding the relationship between overloading and pavement deterioration. A quantitative analysis of the traffic loading trends indicates that overloading is a chief contributor to premature pavement deterioration. This study helps in bringing out a clear picture of the implications of overloading on the design life of a pavement. Estimates of the RSL of the pavement under study which is a section along the Northern Corridor (Athi River to City Cabanas) have been made and it is seen that overloading reduces the pavement service life drastically.

2.10 Conceptual Framework

A conceptual framework helps to organize the flow of research. It aids in achieving the research objectives by explaining the key concepts and the link between them as shown in Figure 2-12 preliminary phase of the study involved developing the research objectives. The research objectives entailed the basic questions that were addressed both quantitatively and qualitatively in this thesis. The next step was to review existing information by analyzing published literature, current and previous studies, and data from national and international agencies. The collection of new data followed. The data sought included traffic loading patterns, road user characteristics, pavement condition data, and traffic and road asset management policies. With significant sample sizes, data coding and entry succeeded. The field data was remoulded into computer-readable style. The data was later analysed to test the research hypothesis. The results of the study were then presented in qualitative and graphical descriptions. The results included the values of the remaining pavement service life in years with regards to the cumulative equivalent single axle load (CESAL) and traffic regulations awareness. The results were discussed and recommendations were made thereafter.

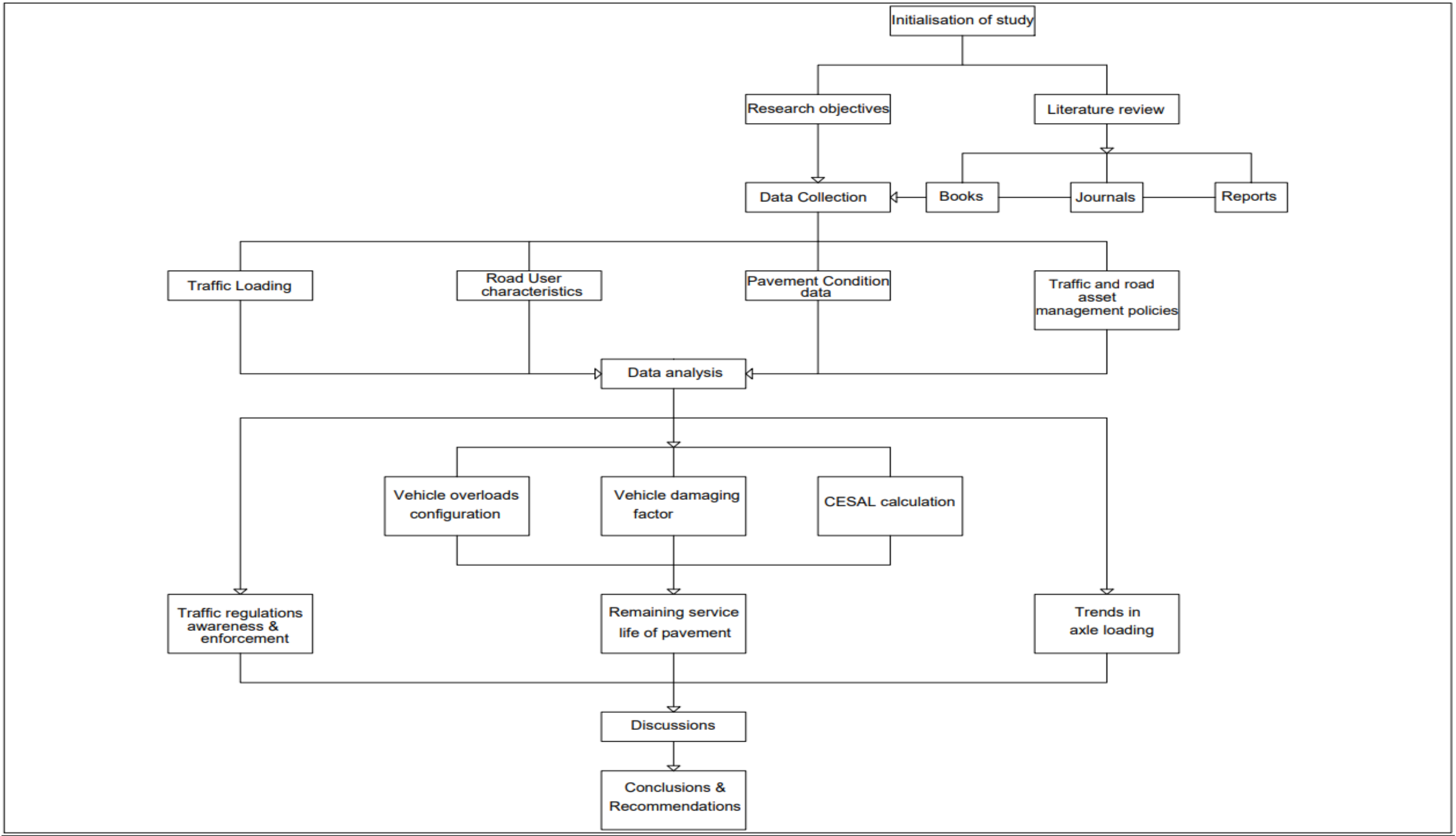


Figure 2-12: Conceptual framework

CHAPTER THREE: MATERIALS AND METHODS

3.1 Evaluation of Traffic Loading Trends

This involved carrying out axle load surveys and field studies on the Northern Corridor Athi River to City Cabanas section and its approaches to collect relevant data on loading patterns. Automatic and manual traffic counts at the weighbridge provided data about the volume of traffic and classification on the Northern Corridor. This data was then used to determine the percentage of overloaded traffic and hence the trends. A summary of the data that was collected is presented in Appendix 1 and Appendix 2.

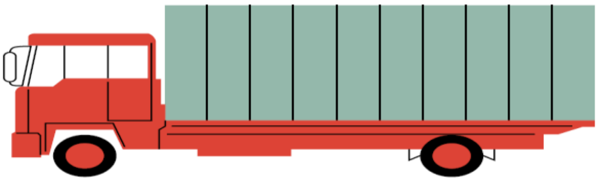
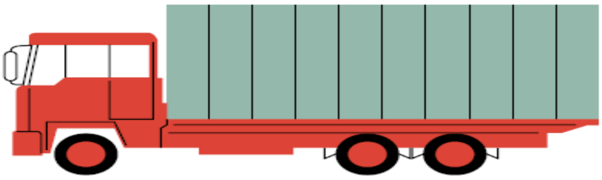
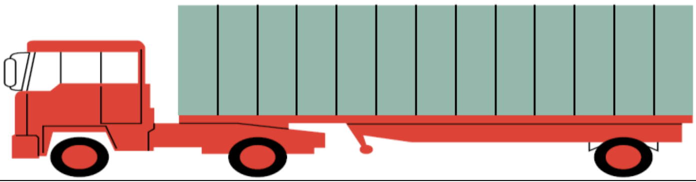
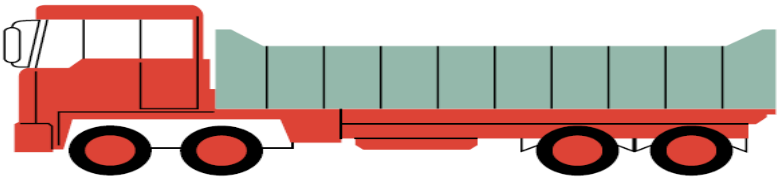
3.1.1 Statistical method and Sampling

To ensure that the data collected was representative of the traffic stream, a good sample design needed to be used. A good sample design ensures that not too much data is collected which is resource-intensive and not too little data is collected which might be inconclusive. If the wrong data is collected, then the results obtained will be meaningless. For the study, the target population defined for sampling was all the heavy goods vehicles (Mombasa bound and Nairobi bound) that passed through the weighbridge at Mlolongo and were weighed. A simple random sampling method was used. By using simple sampling, all goods vehicles in the traffic stream had an equal chance of being chosen for the sample. The method was adopted since it provided a simple and unbiased sample. All vehicles passing through the weighbridge were weighed with the overloaded vehicles being the vehicles of interest to the study. By electronically weighing all goods vehicles, all vehicles had an equal chance of being detected as overloaded. All loaded trucks were electronically weighed. The data from the weighing was then recorded automatically in excel spreadsheets hence eliminating human errors such as transposition errors during data capture.

3.1.2 Data Collection Techniques

The sampled traffic consisted of a variety of axle configurations namely 2A, 3A, 4A, and 6A axle configurations. Some trucks had axles acting in tandem and such were considered as a single axle group. The various configurations are illustrated in Table 3-1.

Table 3-1: Axle configuration chart

Axle Configuration	Illustration
2A Measured as two axle groups	
3A Measured as two axle groups	
3A Measured as three axle groups	
4A Measured as two axle groups	
6A Measured as three axle groups	

The data that was collected was: Truck Gross Vehicle Weight (GVW), individual axle loading, load type, destination, truck axle configuration, and time of data collection.

To assess the loading patterns, a weighbridge was used to weigh vehicles and their contents. The vehicles were grouped into four categories i.e.

i. Total Traffic – These comprised of the total trucks detected as loaded by the load sensor.
ii. Total overload – Out of the total traffic, these are the overloaded trucks either overall gross vehicle weight or on the axles.
iii. Traffic impounded & prohibited – Out of the total overload, these are the trucks that redistributing the load could not solve the overload and therefore need a reliever truck. This means they are blocked at the weighbridge yard, charged, relieved, and thereafter released.
iv. Exempted traffic – These are trucks that are overloaded but are within the acceptable range of overload.

The vehicles were weighed over a static weighbridge which was complimented by a mobile weighbridge unit. The mobile weighbridge was used to target vehicles that might have been avoiding the static weighbridge. The team situated at the Mlolongo weighbridge collected data on the loads carried by the vehicle drivers heading to various destinations.

The procedure outlined below was used in weighing the trucks at the weighbridge.

i. The trucks joined a lane designated for overloading checks. The designated lane had weigh-in-motion sensors erected that check whether the vehicle is loaded. If the weigh-in-motion sensor detected loading, it signalled to the driver to branch to the weighbridge as indicated on Plate 3-1. If the sensor detected an overloaded truck, a red arrow indicating that the vehicle was loaded and should enter the weighbridge was displayed and if no loading was detected, a green arrow was displayed indicating that the driver should proceed without entering the weighbridge.

Plate 3-1: Weigh-in motion sensor
Source: Author

ii. Vehicles entered the weighbridge and the operators checked if the Gross Vehicle Weight was below the limit or above it but within a 5% tolerance as indicated on Plate 3-2 below. If a vehicle was found to be loaded past the allowable gross vehicle weight limit, the driver was instructed to drive to the impoundment yard.

iii. Each axle or axle group of the vehicle was also checked to ensure that the axles were within the limits for individual axles/group axle. During transit, the cargo may move due to the vehicle’s motion. Consequently, some axles can become overloaded and this requires redistribution of the loads to avoid pavement deterioration.

Plate 3-2: Weighing of a truck in progress.
Source: Author

iv. Vehicles found to be overloaded on a specific axle but below the gross vehicle weight were informed on the overloaded axle and by what amount and instructed to proceed to the weighbridge yard to redistribute the load such that no axle is overloaded.
v. After redistribution of cargo, the drivers were required to drive back to the weighbridge for a second inspection. If the weighbridge operator is satisfied with the individual axle loading, then consent for the driver to proceed was given.

3.1.3 Data Analysis and Presentation

Data analysis is important as it is used to test the hypothesis that was set during conceptualisation and planning of the study. Data collected was analysed using spreadsheets and graph generating tools available in Microsoft excel with quantitative data analysed using quantitative analysis techniques using spreadsheets in Microsoft excel. Numerical tabulations were adopted as a way to present large volumes of precise data. Graphs and charts were adopted to present the data to ensure that the data was easy to understand.

3.2 Evaluation of Impact of overloading on Pavement Service Life

Damage to the pavement is caused by many factors starting from the construction phase, usage, environmental factors, but the main factor that causes rapid pavement deterioration in the area under study is overloading. Overloaded vehicles cause damage to roads which leads to higher maintenance and repair costs. This places an additional burden on the state as well as road users who will ultimately bear the brunt of maintenance through fuel levies and other taxes. With dwindling budgets for road rehabilitation and deteriorating road infrastructure, the sound course of action to attain the service life of our roads would be to enforce gross vehicle weight (GVW) and axle load controls on the existing road infrastructure. For this reason, it was important to quantify the damage caused by overloading to better understand the effect of overloading on pavement life and therefore formulate better and more targeted measures to curb pavement deterioration due to overloading. From an initial study, premature pavement deterioration was quantified per research conducted at the AASHO Road Test (Jacob, 2020). The test evaluated damage in terms of equivalent single axle loads (ESALs) from the overloaded trucks basing predictions of overload damage on the 'fourth power rule' that was developed in the late 1950s (Jacob, 2020).

The primary data needed for the estimation of the effects of overloading in this study was the axle loading of various vehicles, traffic vehicular data including the GVW of all vehicle classes that were sampled. The secondary data needed for the estimation included the pavement design life and the traffic growth rate. This data was used to predict the Remaining Service Life of a pavement (Jacob, 2020). The procedure followed in calculating remaining service life was as follows:

i. The Vehicle Damaging Factor (VDF) for each configuration was calculated using the equation

$$VDF = k\left(\frac{Q_i}{Q_s}\right)^4 \quad (2\text{-}5)$$

Standard VDF values are generally determined by a country's road regulatory authorities based on GVW limits. The VDF values that can be used for some of the axle configurations are given in Table 3-2 below:

Table 3-2: Standard VDF values (Jacob, 2020)

Class of Vehicle	**Standard Vehicle Damage Factor**
2-axle	3.898
3-axle	3.679
4-axle	5.934
5-axle	6.222
6-axle	6.003

ii. The cumulative equivalent single axle loads (CESAL) was then calculated using the equation $W_{18} = \sum_{j=1}^{n} N_j \times VDF_j \times D_D \times D_L \times 365$

iii. The values of D_D and D_L which are the adjustment factors for direction and lanes were obtained from Figure 3-1 and Figure 3-2 below:

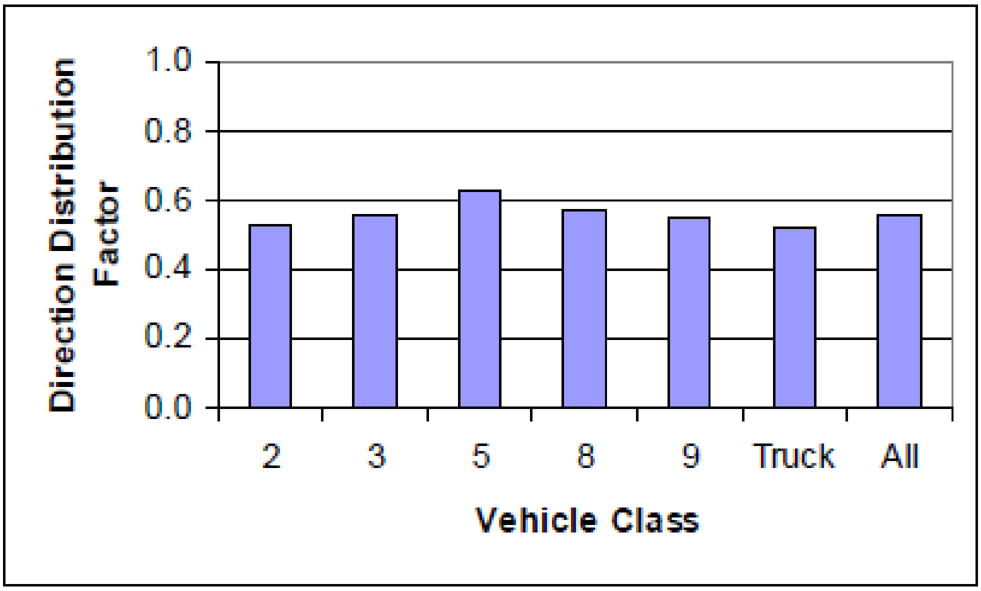


Figure 3-1: Figure showing directional adjustment factor D_D (ERES Consultants Division, 2004)

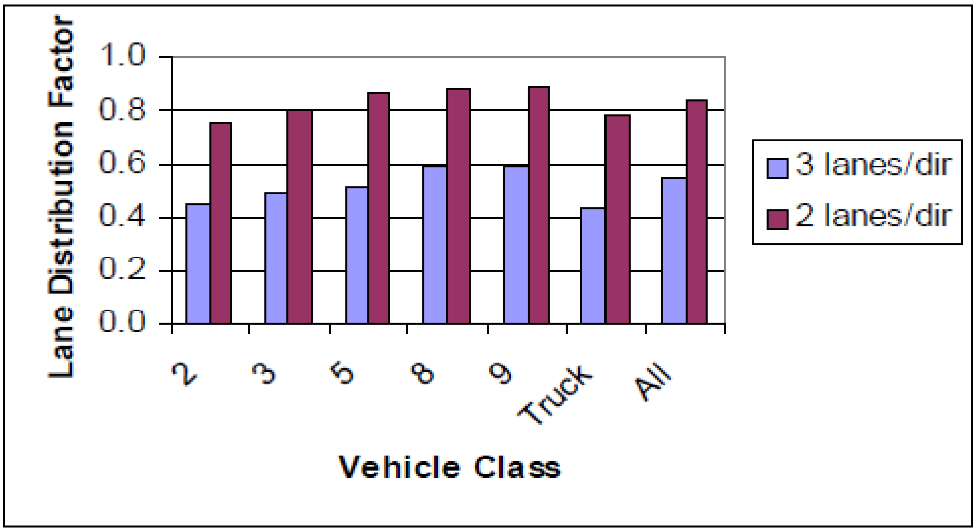


Figure 3-2: Lane distribution factor D_L (ERES Consultants Division, 2004)

iv. The remaining service life was calculated using the formula:

$$RSL = \frac{CESAL_{Standard}}{CESAL_{Overloaded}} \times DL$$

DL – Pavement design life

3.3 Visual Analysis of Pavement Deterioration

Visual analysis was relied on as a way to identify cases of pavement deterioration along the section under study. This was done by travelling along the section under study and visually identifying pavement deterioration. The deterioration that was identified was then photographically documented.

3.4 Questionnaire Data Collection and Analysis

As part of the study, questionnaires were provided to transporters to get their view on overloading, knowledge about axle load limits, penalties, and why they still overload. The questionnaires were designed to help understand the attitudes and awareness of transporters and how that affects overloading. Using the data gathered using questionnaires, it would then be possible to come up with solutions that address overloading targeted at transporters in addition to existing load limits. The questionnaire data was collected at Athi River (Mlolongo Weighbridge). The questionnaires were administered to long and short-distance drivers at the weighbridge. Vehicles with different axle configurations were sampled to get results covering as many variations in traffic as possible.

The questionnaire was structured to have short answer questions due to limitations in time where one could interact with respondents. It consisted of fourteen main questions which were designed to take not more than three minutes to fully answer. The types of questions were:

i. Demographic Questions – These are questions designed to get basic personal information about the respondent. These questions help determine if certain tendencies from those under study could be a result of personal factors. For example, knowledge of axle limits can be checked against experience in cargo transport to determine if more years in the sector had any bearing on the awareness of respondents about axle load limits and penalties or lack thereof.
ii. Closed-ended questions – These questions consist of one-word answers, basically yes or no. These formed the majority of the questions. They ensure consistency of data for easier analysis. They also served to save time due to the time limitations for each questionnaire.
iii. Open-ended questions – These are questions meant to open up the conversation by allowing respondents to structure their answers as they wish and to give personal opinions on the subject. Open-ended questions were not widely used in the questionnaire.

The questionnaire that was used in the study is shown in Appendix 4.

3.4.1 Sampling Design

For the questionnaire, the questionnaire study objectives were defined first. By defining the objectives, it was possible to develop the basic questions to be answered both qualitatively and quantitatively. For this study, the target population for the sampling was drivers as they entered the weighbridge. Simple random sampling was adopted for the questionnaire study. In this method, a sample is selected such that each possible sample of the target population has an equal chance of being chosen. The transporters who were interviewed for the questionnaires were randomly selected in a manner such that they were representative of the entire sample and that each had an equal chance of being selected.

Sample size selection involves a trade-off. A larger sample gives more accurate results whose reliability increases with size. However, a larger sample size means more costs are incurred for data collection and analysis. It is, therefore, necessary to balance reliability and sample size when it comes to data collection. The sample size was determined using the sample selection formula (Spiegel, Schiller, & Srinivasan, Probability and Statistics, 2009):

$$n = \frac{(Z - score)^2 \; x \; Standard \; Deviation \; x \; (1 - Standard \; Deviation)}{(Confidence \; Interval)^2}$$

n – Sample size

The margin of error (Confidence interval) – Since no sample is perfect, the confidence level allows for error in the sample. It can be defined as an expression of the degree of uncertainty in the sampling method. Simply it tells how confident one is that results from a study will reflect what one would expect to find if the entire population was studied and is expressed as a plus or minus figure. The margin of error should be as small as possible. The margin of error selected for this survey was ± 6%.

Confidence level – It expresses the percentage of probability of confidence with which the actual mean would fall within the confidence interval. For computation purposes, the confidence level is converted to a Z-score using tables. A confidence level of 90% was chosen for the questionnaire survey which has a corresponding Z-score of 1.645 (Spiegel, Lipschutz, & Liu, Mathematical Handbook of Formulas and Tables, 2013).

Standard deviation – It is a measure of a data sets distribution from its mean or simply how much variance one can expect in the responses. A value of 0.5 can be typically used to ensure that the sample size is sufficiently large. For this study, 0.5 was used as the standard deviation.

$$n = \frac{(1.645)^2 \; x \; 0.5 \; x \; (1 - 0.5)}{(0.06)^2} = \; 187.9$$

200 samples were therefore settled on as appropriate for the questionnaire study.

Data collected was analysed using spreadsheets and graph generating tools available in Microsoft excel with quantitative data analysed using quantitative analysis techniques using spreadsheets in Microsoft excel.

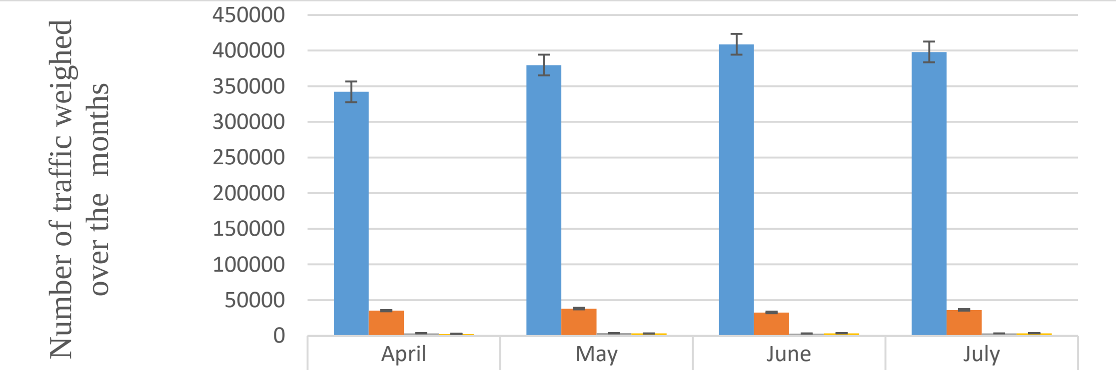
CHAPTER FOUR: RESULTS, ANALYSIS AND DISCUSSIONS

4.1 Introduction to Results and Discussions

Axle load surveys on the Northern Corridor Athi River – City Cabanas section were carried out to determine traffic loading trends using static and mobile weighbridges. Loading data was collected for April – July 2020. At the static weighbridge, all loaded trucks were weighed and the loading data recorded. For the mobile weighbridge, trucks were randomly stopped and weighed if they were suspected to be overloaded. The loaded heavy goods vehicles were weighed to come up with loading data for both the Nairobi and Mombasa bound traffic. Using the loading data, the trends for overloading were developed. The loading data was thereafter used to determine the impact of overloading on pavement service life using the fourth power rule. Questionnaires were also distributed randomly to truck drivers as they entered the weighbridge. They were used to assess awareness of transporters on axle load limits and their views on overloading and how that affects overloading and road use.

4.2 Loading Trends from Static Weighbridge Data.

Heavy goods vehicles were weighed at the static weighbridge. Overloads for each vehicle were assessed by checking the axle loading of the trucks and comparing it to the allowable axle loads. The Gross vehicle weight for each vehicle was also assessed. Among the overloaded vehicles, some were impounded and prohibited and were required to pay a fine and correct the overload using a relief truck. Some vehicles had special permits based on the type of cargo being transported and were therefore allowed to proceed. A summary of loading data for the months in which the study was conducted has been summarised in Figure 4-1 below.



	April	May	June	July
Total Traffic	342065	379600	408800	398000
Total Overload	35232	37971	32674	36237
Impounded & Prohibited	3546	3706	3152	3423
Exempted	2691	3197	3568	3456

Figure 4-1: Traffic trends at the static weighbridge (2020)

The error bars in Figure 4-2 indicate a fairly small spread of the studied data making the variations in overloading over the study period significant. Error bars indicate the spread of data, variability, or uncertainty in a certain measurement and they can also reveal whether data is insufficient and if ineffective research methods were used during the research (Bleier, 2020). Intense overlapping of the error bars may indicate insignificance in the variations of the study results whereas small overlaps may indicate a significance in the variations of the study results (Bleier, 2020).

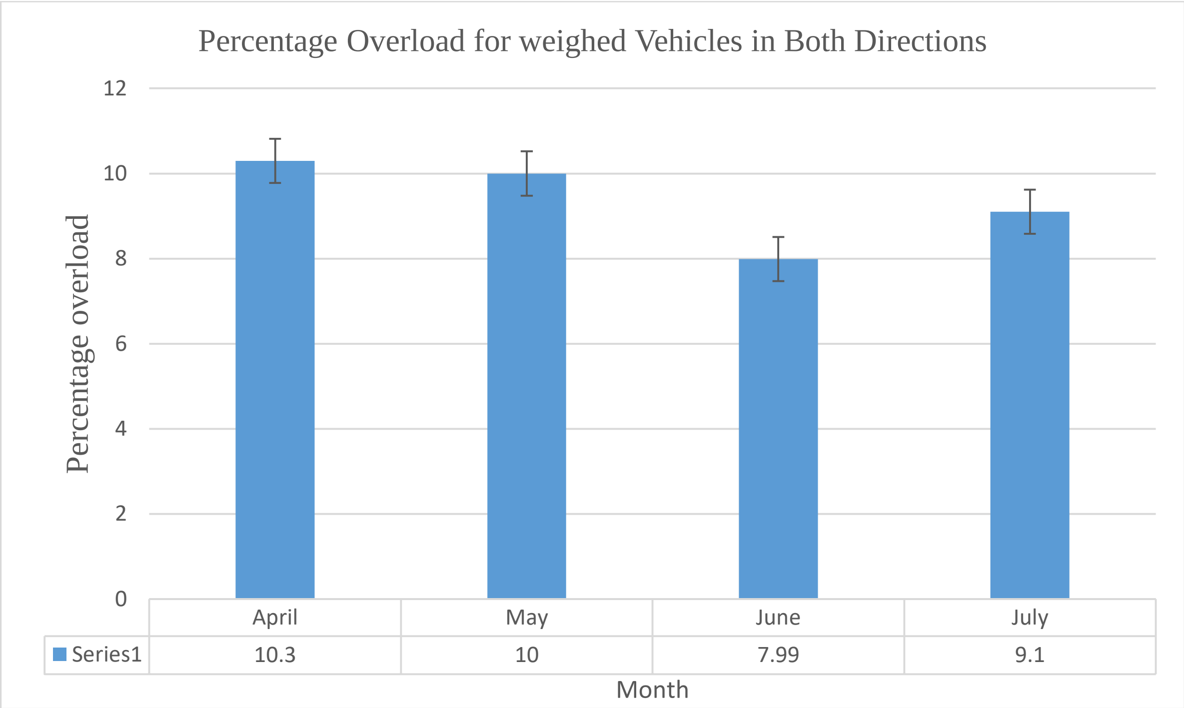


Figure 4-2: Percentage overload for weighed vehicles in both directions (2020)

From Figure 4-2, April had the highest percentage overload while June had the lowest percentage overload. By determining the percentage overloads for each month, loading monitoring and axle load limit enforcement can be adapted to monthly variations in overload rates. Enforcers can be informed on how overloading trends vary per month whereby they can then monitor loading as needed. From Figure 4-2, the error bars have small overlaps making the variations of percentage overload during the study period significant.

4.2.1 The Trend for Nairobi Bound Traffic

Data for the four months was collected at the static weighbridge for Nairobi bound traffic. The data was presented in a chart as shown in Figure 4-3.

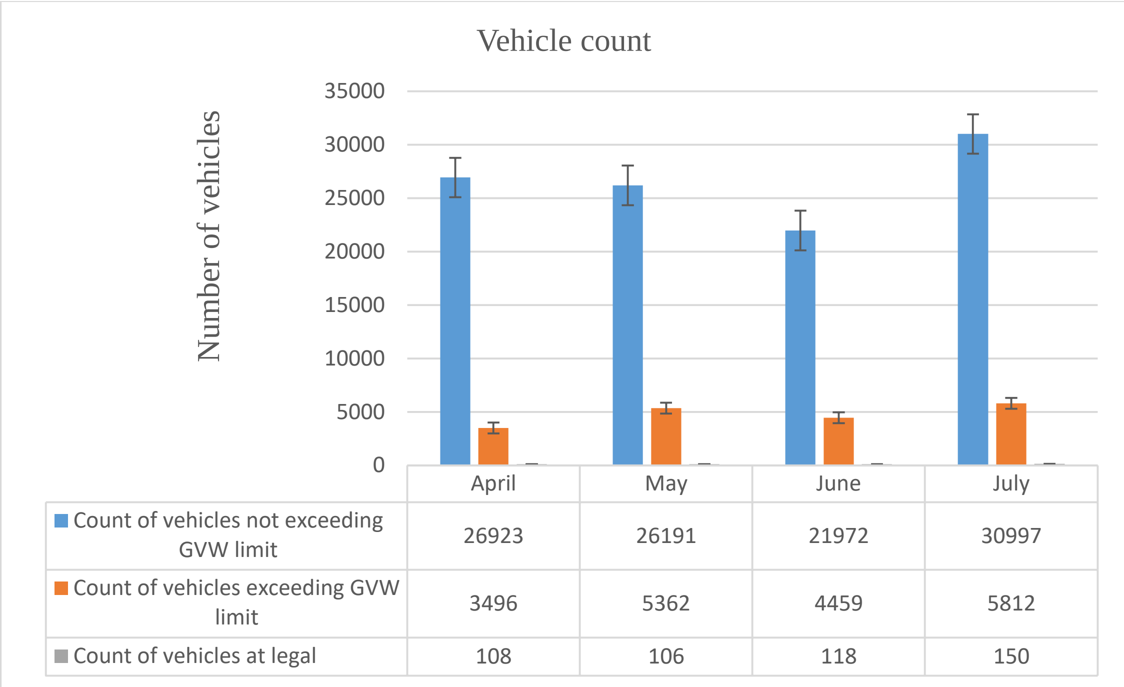


Figure 4-3: Traffic trends at static weighbridge for Nairobi Bound Traffic (2020)

Using the traffic loading counts, Figure 4-4 which shows the percentage overload for each month was developed. The percentage overload allows simpler interpretation of overloading as opposed to raw count data.

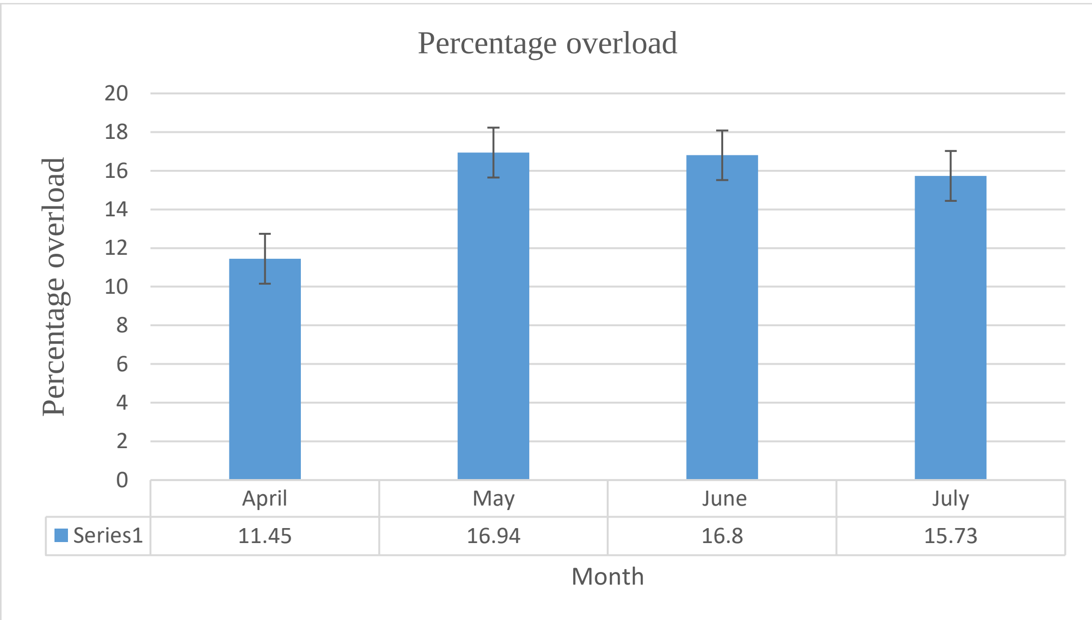
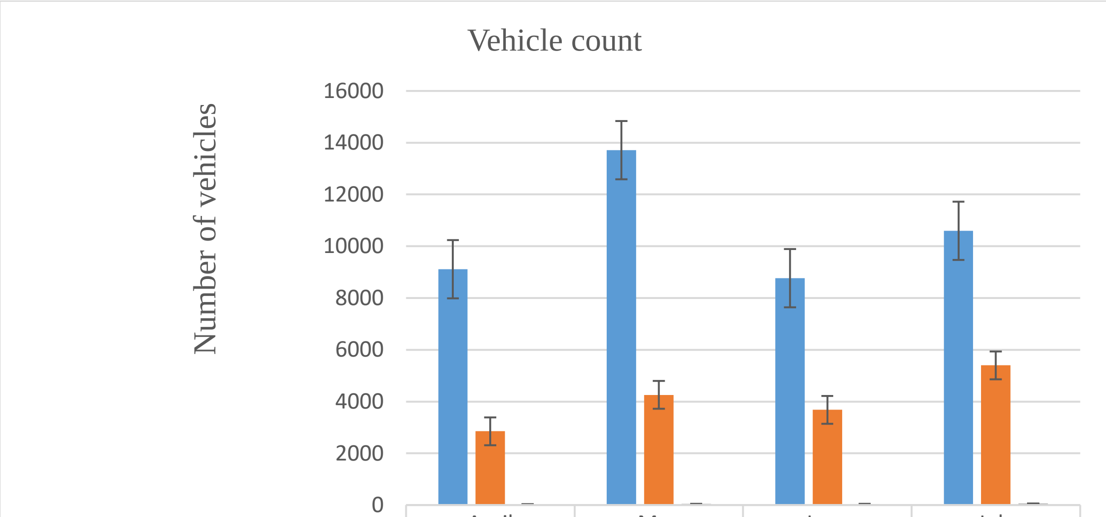


Figure 4-4: Percentage overload for Nairobi bound traffic (2020)

From Figure 4-34, more of the Nairobi bound drivers observed the GVW limits as compared to those headed to Mombasa as shown in Figure 4-66Figure 4-5. The number of vehicles overloaded changes month-wise with May having the highest percentage overload and April the lowest. The relatively low overload rate for Nairobi-bound traffic can be attributed to the fact that most of this traffic originates from Mombasa and passes through the Mariakani weighbridge where overloads are detected before the traffic gets to the Mlolongo weighbridge. Using the loading trends, targeted measures to address overloading can be used which can be customised for each month. The overlaps in the error bars are not intense and thus we can conclude that the variations in overloading over the study period are significant.

4.2.2 The Trend for Mombasa Bound Traffic

Data for the four months was collected at the static weighbridge for Mombasa bound traffic. The data was thereafter analysed and presented as in Figure 4-5.



	April	May	June	July
Count of vehicles not exceeding GVW limit	9109	13707	8763	10592
Count of vehicles exceeding GVW limit	2852	4258	3681	5399
Count of vehicles at legal	32	48	41	58

Figure 4-5: Traffic Trends for Static Weighbridge for Mombasa Bound Traffic

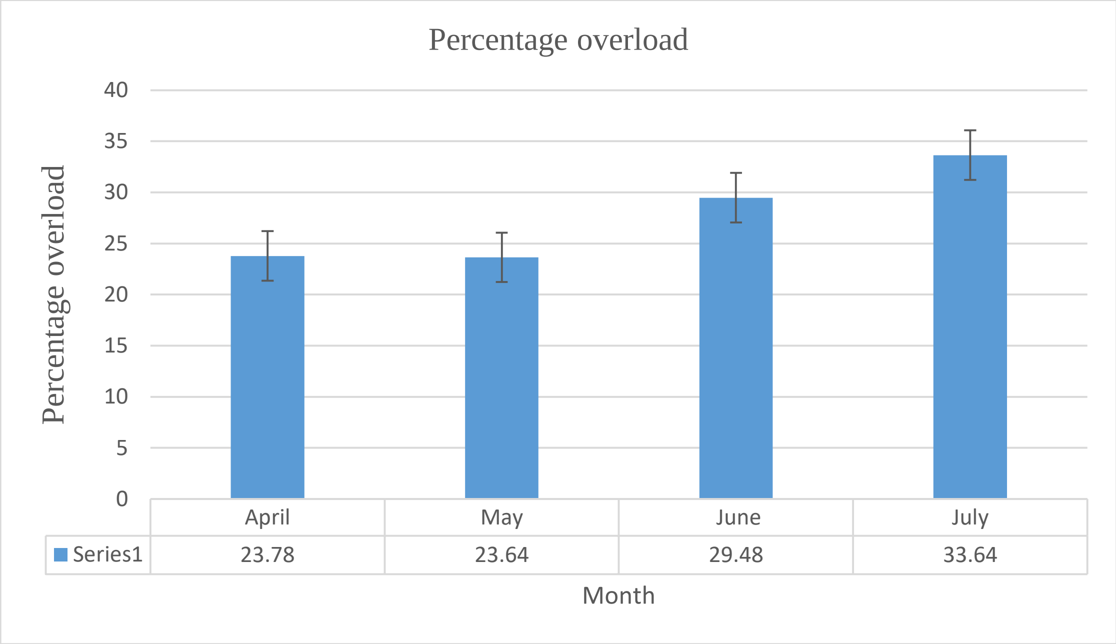


Figure 4-6: Percentage overload for Mombasa bound traffic

The number of overloaded vehicles in the Mombasa direction varies month-wise as seen in Figure 4-5 with July having the highest percentage overload while May having the lowest. The study results do not have intensely overlapping error bars. Therefore, variations in overloading over the period of study are significant. These results can help traffic management officials to plan for better ways to curb overloading. The results can be used to make changes in enforcement activities by highlighting critical periods when overloading is at its peak.

4.2.3 Individual Axle Percentage Overloads for Nairobi Bound Traffic

To determine individual axle overload rates, the data was analysed to get the overload rate for each vehicle configuration per axle per month. Table Summaries for the axle overloads are presented in Appendix 2.

Individual axle overload rates for Nairobi bound traffic 2A configuration are show in Figure 4-7 below.

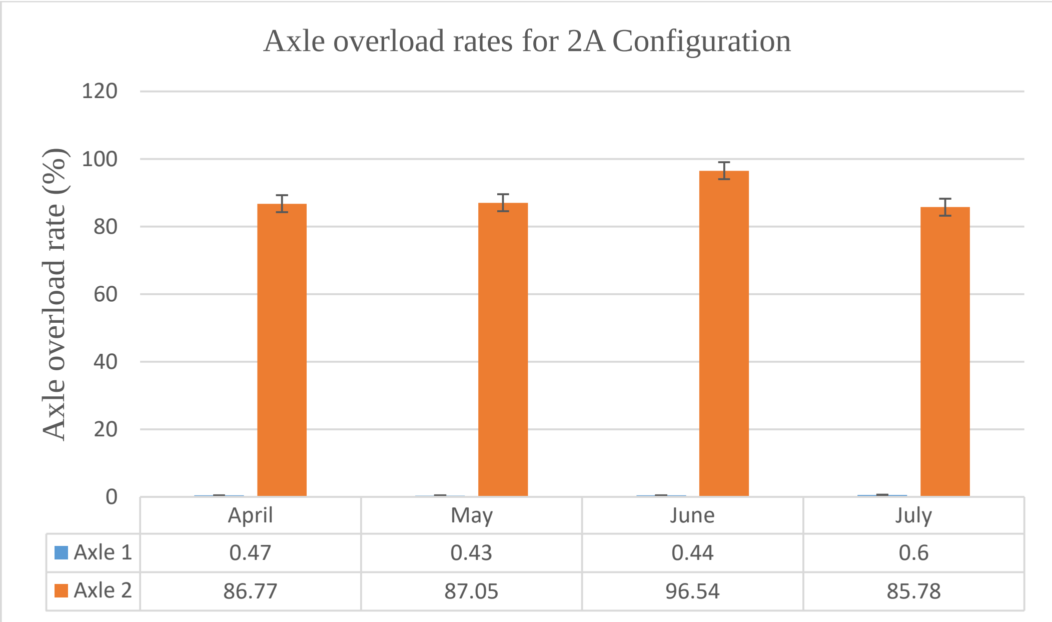
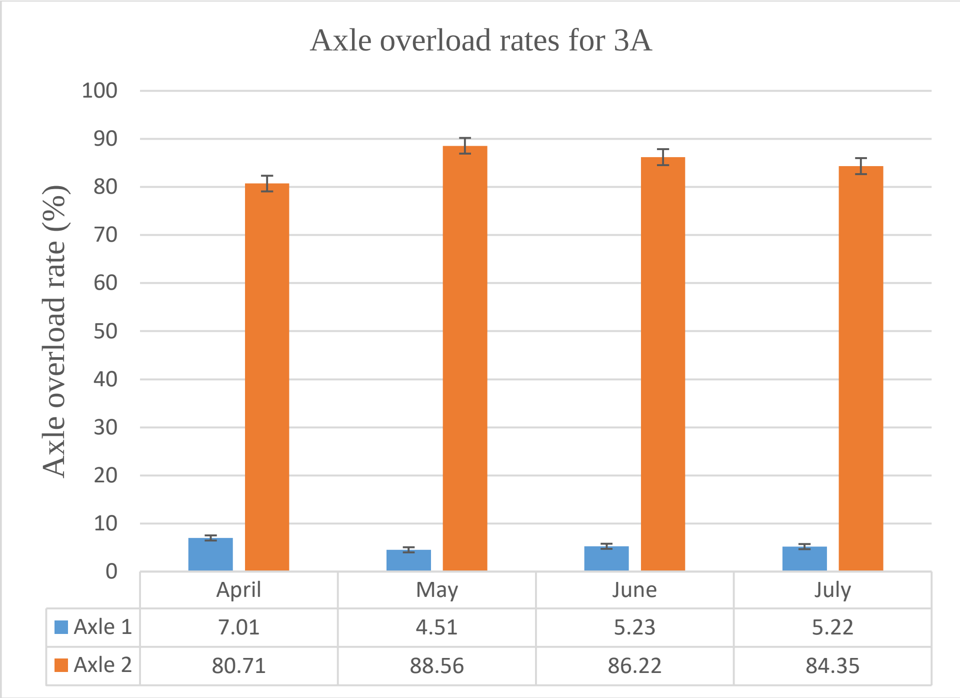


Figure 4-7: Axle overload rates for 2A configuration (Nairobi Bound Traffic)

For the 2A configuration, axle 1 which was the steering axle was found to have a very low rate of overload with the highest being 0.6%. Axle 2 which is the rear axle on the other hand had a very high overload rate with the lowest being 85.78% in the month of July and the highest being 96.54%. The high difference in overload rates between axle 1 and axle 2 can be indicative of an improper load distribution among the axles. Uneven distribution of the loads between the axles even when the vehicle gross weight might be within the limit is considered as overloading. Overloading causes excess distress on the pavement as the overloaded axle causes excess stress on the pavement. The use of variable tyre pressure can help to reduce the effect of overloading (Philip O & Anton H, 2001). The values and rates of overloads can be used in conjunction with variable tyre pressures to model pavement response. The optimum tyre pressure values can be used to programme central tyre inflation systems which can be used in vehicles to mitigate the effect of overloading and repeated loading. Once the critical axle has been identified, modifications can be made to reduce the impacts of overloads on the pavement. The error bars indicate that the variations in axle overloading are significant. Vehicle fabrication may also be a contributing factor to the uneven load distribution as the overload rates between the rear and front axles were found to vary widely. It is therefore necessary to work with fabricators to ensure load distribution among axles is even.

Figure 4-8 shows the individual axle overload rates for vehicles with a 3A configuration,



	April	May	June	July
Axle 1	7.01	4.51	5.23	5.22
Axle 2	80.71	88.56	86.22	84.35

Figure 4-8: Axle overload rates for 3A configuration (Nairobi Bound Traffic)

The trucks that were sampled with a 3A configuration had one driving axle and two rear tandem axles. The tandem axles were weighed together as a single axle group whose limit was 18,000 Kgs. For the 3A configuration, axle 1 had relatively low rates of overload with the lowest being 4.51% in the month of May and 7.01% being the highest and was recorded in the month of April. The most overloaded axle among 3A configuration vehicles in the Nairobi direction is the second axle as shown in Figure 4-8. The variations in axle overloading are significant since the error bars have a fairly small spread. There is no intense overlapping of the error bars. The rates of axle overloading can be used to design for vehicles with adjustable tyre pressures which help in mitigating overloading. During vehicle fabrication, load distribution between the rear and front axles should be considered as a key design parameter.

Individual axle overload rates for Nairobi bound traffic 4A configuration are show in Figure 4-79 below.

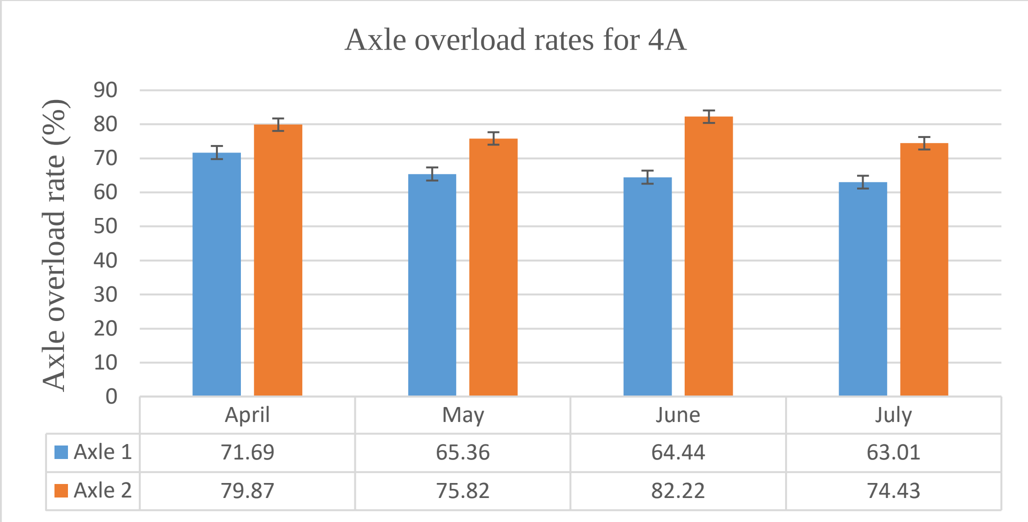


Figure 4-9: Axle overload rates for 4A configuration (Nairobi Bound Traffic)

The 4A configuration had the highest overload rates for axle 1 among all the various configurations. The highest overload rate for axle 1 was in the month of April which was 71.69%. For axle 2, the highest overload rate was in the month of April which was 82.22%. The error bars in Figure 4-9 indicate a fairly small spread of the results. This indicates that the variations in the axle overload rates are significant.

Individual axle overload rates for Nairobi bound traffic 6A configuration are show in Figure 4-710 below.

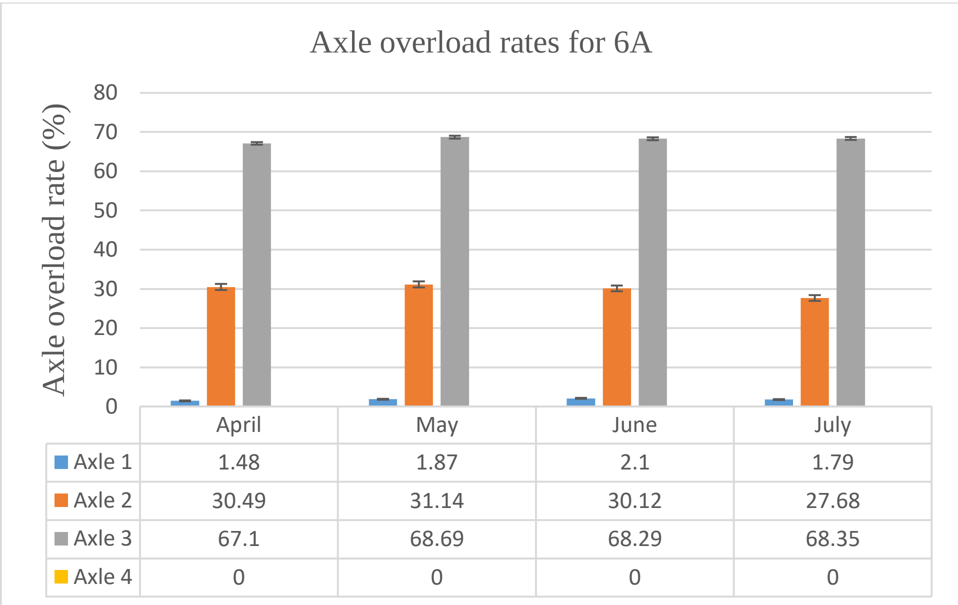


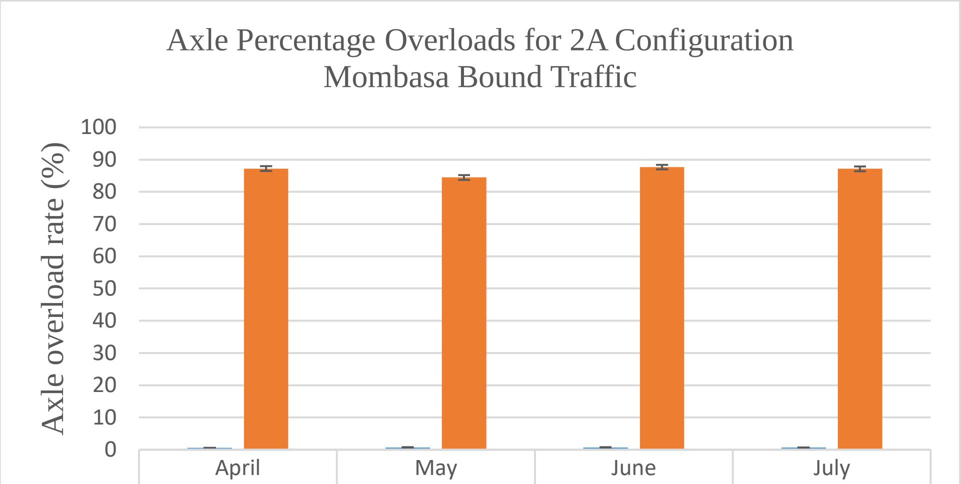
Figure 4-10: Axle overload rates for 6A configuration (Nairobi Bound Traffic)

For the 6A configuration, Axle 3 was the most overloaded axle. No overloads were recorded for Axle 4 in any of the months under study. Axle 1 had a relatively low overload rate.

4.2.4 Individual Axle Percentage Overloads for Mombasa Bound Traffic

To determine axle overload rates, the data was analysed to get the overload rate for each vehicle configuration per axle per month for Mombasa bound traffic. Table summaries of the overload rates are presented in Appendix 2.

Individual axle overload rates for Mombasa bound traffic 2A configuration are show in Figure 4-11 below.



	April	May	June	July
Axle 1	0.55	0.71	0.71	0.65
Axle 2	87.2	84.47	87.67	87.14

Figure 4-11: Axle overload rates for 2A configuration (Mombasa Bound Traffic)

For the 2A, axle 1 which was the steering axle was found to have a very low rate of overload with the highest being 0.71% and the lowest being 0.55%. Axle 2 had a very high overload rate with the lowest being 84.47% recorded in May and the highest being 87.67% recorded in June. The high difference in overload rates between axle 1 and axle 2 is indicative of an improper load distribution among the axles. This should be considered during vehicle fabrication to ensure that load is properly distributed among axles to prevent the high overload rates on the rear axle while the front axle has a very low overload rate.

Individual axle overload rates for Mombasa bound traffic 3A configuration are show in Figure 4-12 below.

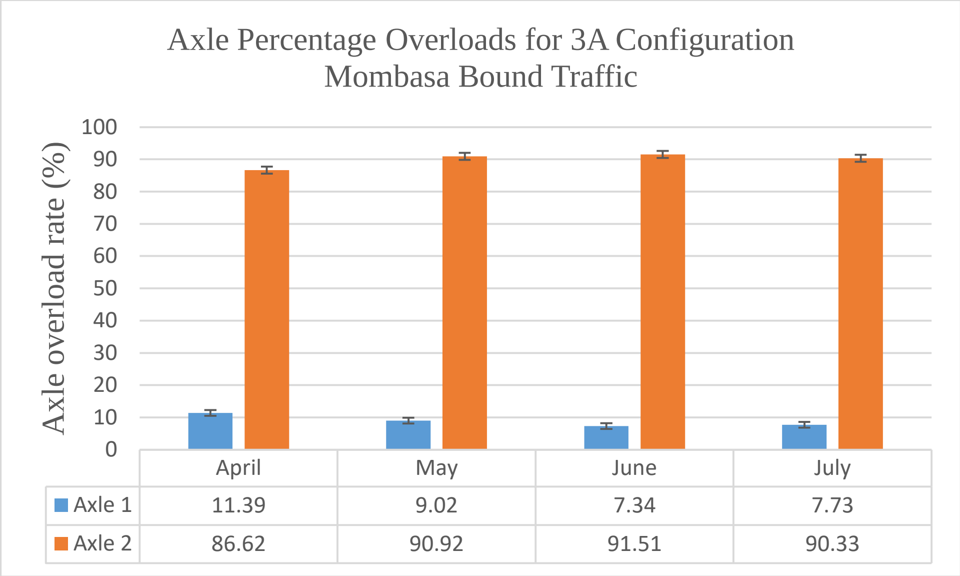


Figure 4-12: Axle overload rates for 3A configuration (Mombasa Bound Traffic)

For the 3A configuration, axle 1 had relatively low rates of overload with the lowest being 7.34% in the month of June and 11.39% being the highest and was recorded in the month of April. Axle 2 had high overload rates for the 3A configuration. April had the lowest overload rate for 3A at 86.62% and June had the highest rate for axle 2 at 91.51%. There is a high difference in overload rates among the front axle and rear axles. This may be due to issues with fabrication leading to improper load distribution.

Individual axle overload rates for Mombasa bound traffic 4A configuration are show in Figure 4-13 below.

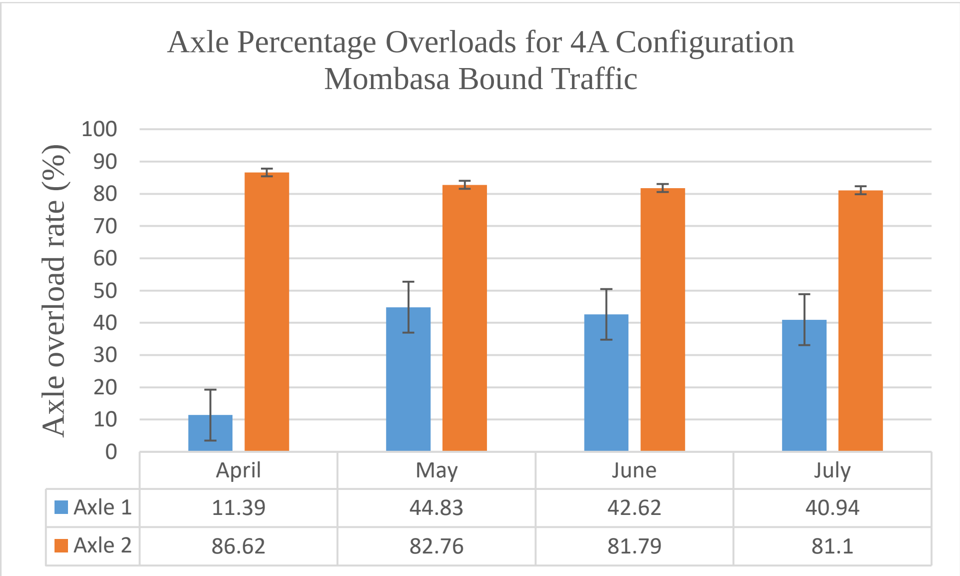


Figure 4-13: Axle overload rates for 4A configuration (Mombasa Bound Traffic)

The 4A configuration had the highest overload rates for axle 1 among all the various configurations for Mombasa bound traffic. The highest overload rate for axle 1 was in the month of May which was 44.83% and the lowest was 11.39% for April. For axle 2, the highest overload rate was in the month of April which was 86.62%.

Individual axle overload rates for Mombasa bound traffic 6A configuration are show in Figure 4-14 below.

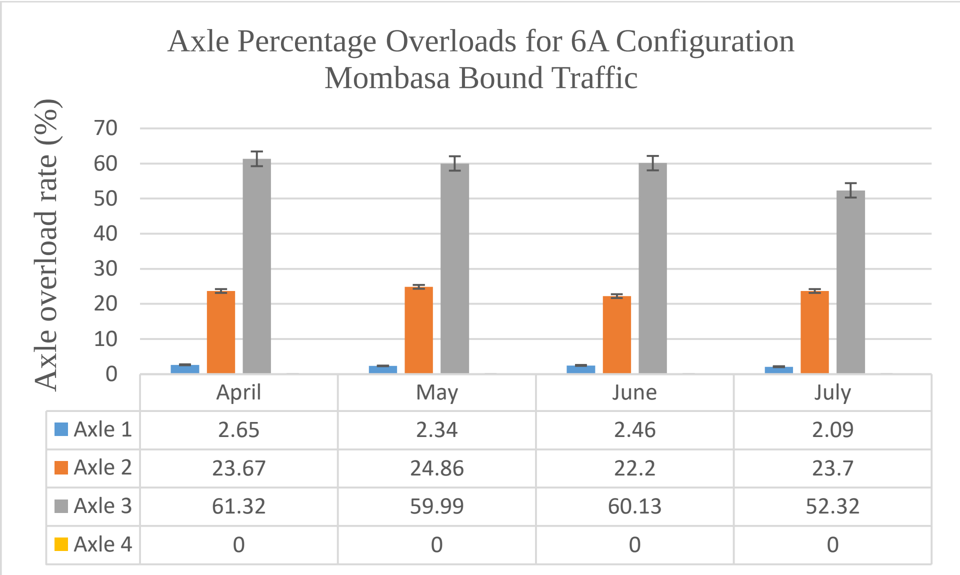


Figure 4-14: Axle overload rates for 6A configuration (Mombasa Bound Traffic)

For the 6A configuration, Axle 3 was the most overloaded axle. No overloads were recorded for Axle 4 in any of the months under study. Axle 1 had a relatively low overload rate while axle 2 had moderate overload.

It was observed during the period under study that some axles were barely ever overloaded while some experienced very high rates of overloading. In cases where individual axles were overloaded, the load on the pavement exceeded the load used in pavement design causing stress greater on the pavement structure than that it was designed for. This greater stress caused more fatigue and bending on the pavement leading to premature failure as shown in section 4.5. The load carried by a vehicle should be evenly distributed among the axles and be within the specified gross vehicle weight limits. Regulatory bodies should work with vehicle body manufacturers to ensure load is evenly distributed among the various axles in trucks.

4.3 Traffic Loading as Captured by the Mobile Weighbridge Unit

For the Mlolongo weighbridge a mobile unit is also used whose essence is to capture overloaded trucks that evade the static weighbridge by using alternative routes, feeder roads or the collector roads around the weighbridges. Upon suspicion of overloading, a truck is pulled over by the mobile weighbridge operators and its Gross Vehicle Weight is confirmed. Figure 4-15 shows the data obtained from the mobile unit. A high proportion of vehicles weighed by the mobile unit was found to be overloaded since the mobile unit only stopped vehicles that they suspected of overloading, therefore, increasing the likelihood that a weighed vehicle will have overloaded.

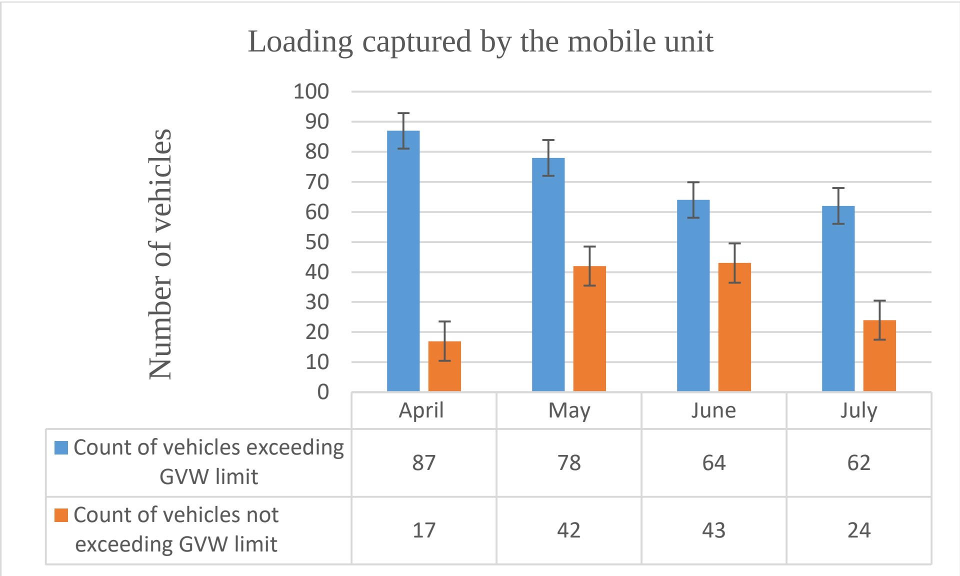


Figure 4-15: Loading captured by the mobile weighbridge

From the figure 4-15, the count of vehicles exceeding legal weight reduces overtime from April to July showing a decreasing trend. The decrease in the count of overloaded vehicles indicates that there was efficient enforcement of traffic loading regulations during the study period. The successful implementation of traffic regulations during the study period can be cited as a benchmark for future enforcement activities. This will help in better traffic and road asset management in the area of study. The error bars show a fairly small spread of the results. This proves that the variations in overloading over the study period are significant

4.3.1 Sand Trucks Evasion of Static Weighbridges

Sand is widely used in construction works as an aggregate in concrete. There has been an increase in demand for sand nationally as many construction projects are being undertaken. Since the study area (Athi River interchange to Mlolongo) has a river with sand deposits, sand harvesting is a major economic activity in this area. After the sand has been collected and loaded onto the transport trucks, it is transported locally and nationally to customers for construction works. It is during transportation of the sand that a substantial number of sand transporters breach loading regulations. Most sand trucks fall under the 2A category of axle configuration and formed a huge chunk of overloaded trucks flagged by the mobile weighbridge operators as shown on Figure 4-16 below.

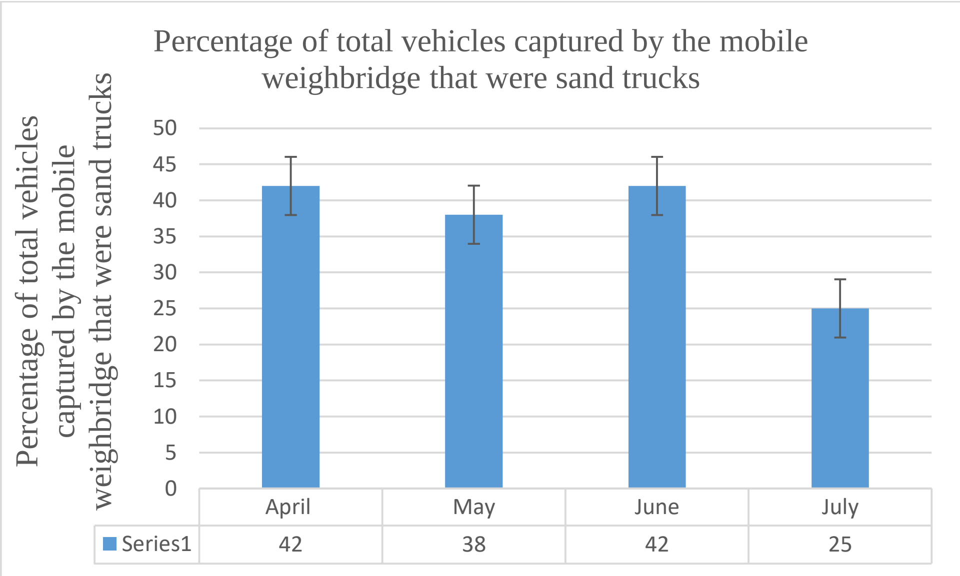


Figure 4-16: Percentage of total vehicles captured by the mobile weighbridge that were sand trucks

Sand truck drivers have a tendency to overload as shown in Figure 4-16. With this information, traffic management officials can monitor the drivers more closely to reduce their tendency of overloading. Measured and policy that specifically targets sand transporters can be instituted to cur overloading. This will help in the preservation of the pavement service life. The variations in the percentage overloads are significant since the error bars do not overlap excessively.

4.4 Comparison of Peak Overload Values

The study focused on the traffic loading characteristics captured by both the static and mobile weighbridges. Figure 4-17 shows the peak overloads for each axle configuration as captured by the static weighbridge.

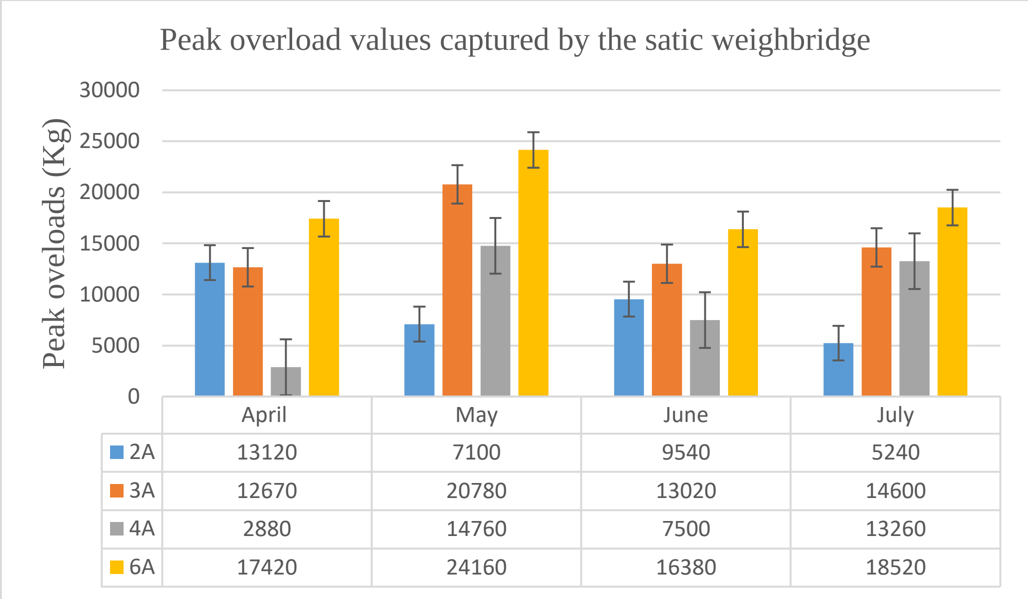


Figure 4-17: Peak overloads captured by the static weighbridge

Peak overloads for each axle configuration as captured by the mobile weighbridge are shown in Figure 4-18.

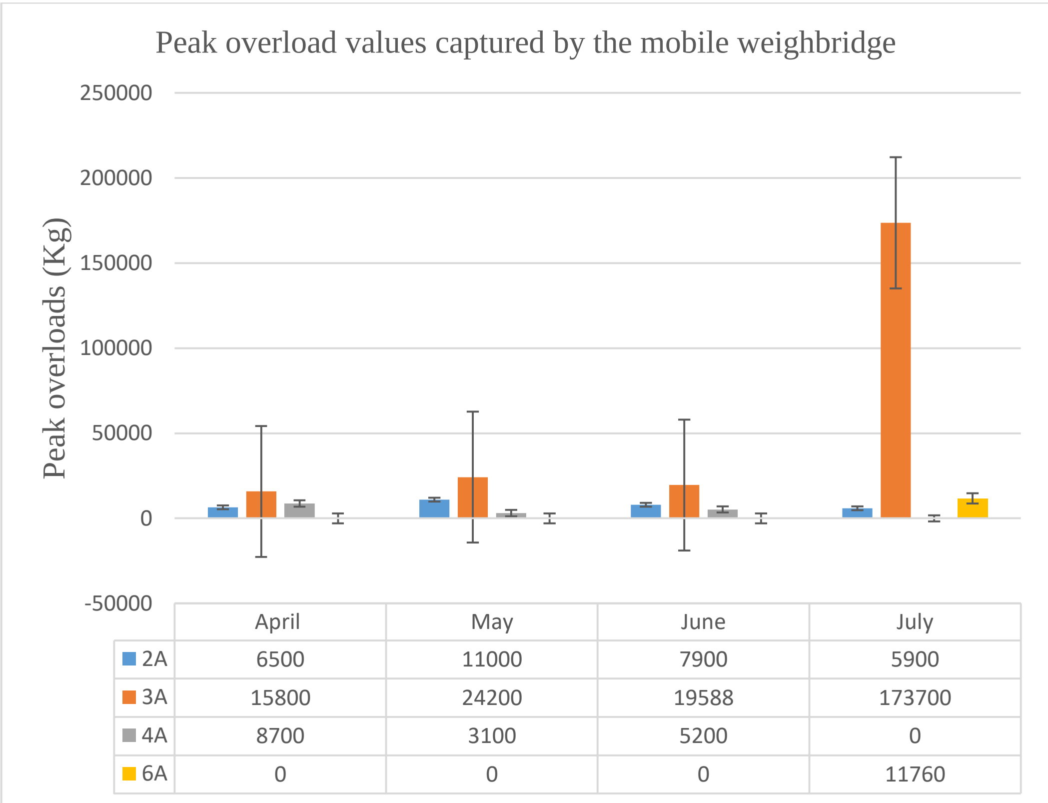


Figure 4-18: Peak overload values captured by the mobile weighbridge

The variations in overloading are significant for the first three months of the study period except for July which has an intense overlap in the error bars. This is due to the lack of an overloading case by a 6A truck.

It can be seen that peak overload values between the static and mobile weighbridge were not very different. However, the rate of overload for trucks weighed by mobile weighbridge is higher than the rate of overload for trucks weighed at the static weighbridge. This could indicate that drivers who avoid the static weighbridge might be aware that they are overloading and hence avoid the weighbridge. This could explain the higher rate of overload among the vehicles sampled by the mobile unit. The values of peak overloads in Figure 4-17 and Figure 4-18 can be used to model pavement response by subjecting the models to loads that represent the heavy traffic. One way to reduce the impact of overloads on the pavement is to design pavements that can carry loads from heavy traffic. The pavement layer thicknesses and the material resilient moduli have been proved to be influential in improving the rutting and fatigue resistance of the pavements. Models can help to identify pavement properties that are crucial in the design of sustainable pavements. The variations in overloading as captured by the static weighbridge are significant as the overlaps in the error bars are not intense.

4.5 Quantitative Estimation of the Impact of Overloading on Pavement Service Life

The impact of loading on a pavement service life can be estimated based on the 4^{th} power formula by AASHTO 1993 equation (Jacob, 2020). Overloaded trucks are a major cause of deterioration on the Northern corridor as the highway is used by both heavy and light good vehicles. This section details the procedure that was used to determine the impact of vehicle loads on pavement life. The procedure that was used for the estimation of the remaining service life is outlined in section 3.2.

4.5.1 The Remaining Pavement Service Life

A summary of calculations is presented in this section. More detailed calculations of Remaining service life are presented in Appendix 3.

i. Remaining Service Life for April, Nairobi bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic in the Nairobi direction for April are presented in Table 4-1 and

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	430	141.7	0.5	0.78	365	8671661
3A	145	10.51	0.5	0.78	365	216965.4
4A	12	5.218	0.5	0.78	365	8913.675
6A	619	7.508	0.5	0.78	365	661607.4
Total						9559148

Table 4-2 respectively. The values of the vehicle damaging factor for the different vehicle axle configurations can be used to identify the most critical axle to pavement failure. The results revealed that the factors for 2-axle vehicles were the greatest followed by the factors for 3-axle vehicles. These results were similar to the results of a study done by Muhammad and Rawid in 2018 (Muhammad R & Rawid K, 2018). Muhammad and Rawid recommended the use of 6-axle semi-trailers as the appropriate heavy goods freight vehicle because of the lower vehicle damaging factor compared to other axle configurations. The greater the damaging factor the greater the pavement damage (Ojha, 2018). The vehicle damaging factors determine the appropriate freight vehicles with minimal pavement destruction.

Table 4-1: Estimated traffic in the design life of pavement (overload)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	430	141.7	0.5	0.78	365	8671661
3A	145	10.51	0.5	0.78	365	216965.4
4A	12	5.218	0.5	0.78	365	8913.675
6A	619	7.508	0.5	0.78	365	661607.4
Total						9559148

Table 4-2: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	430	3.898	0.5	0.78	365	238598.5
3A	145	3.679	0.5	0.78	365	75937.32
4A	12	5.934	0.5	0.78	365	10136.46
6A	619	6.003	0.5	0.78	365	528952.2
Total						853624.6

$$RSL = \frac{\mathbf{853624.6}}{\mathbf{9559148}} \times \mathbf{15} = \mathbf{1.339}$$

From the RSL calculations, it was found that the pavement with a design period of 15 years if subjected to repetitive loadings of the magnitude used in the calculations, then the pavement service life would be reduced to approximately 1 year and 4 months after which it would require major rehabilitation. The remaining service life values can be used to programme and schedule timely pavement maintenance and rehabilitation activities. The predictions can help to plan for pavement rehabilitation activities to minimise further pavement damage.

ii. Remaining Service Life for May, Nairobi bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented in Table 4-3 and

Table 4-4 respectively.

Table 4-3: Estimated traffic in the design life of pavement (overload)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	306	152.2	0.5	0.78	365	6630469
3A	37	9.018	0.5	0.78	365	47496.06
4A	2	6.005	0.5	0.78	365	1709.485
6A	515	6.191	0.5	0.78	365	453840.9
Total						7133515

Table 4-4: Estimated traffic in the design life of pavement (standard)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	306	3.898	0.5	0.78	365	169793.4
3A	37	3.679	0.5	0.78	365	19377.11
4A	2	5.934	0.5	0.78	365	1689.41
6A	515	6.003	0.5	0.78	365	440081.4
Total						630941.3

$$RSL = \frac{\mathbf{630941.3}}{\mathbf{7133515}} \times \mathbf{15} = \mathbf{1.327}$$

iii. Remaining Service Life for June, Nairobi bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented in Table 4-5 and Table 4-6 respectively.

Table 4-5: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	278	113.3	0.5	0.78	365	4483368
3A	87	10.04	0.5	0.78	365	124405.1
4A	2	4.293	0.5	0.78	365	1222.217
6A	627	7.618	0.5	0.78	365	679923.4
Total						5288918

Table 4-6: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	278	3.898	0.5	0.78	365	154256.7
3A	87	3.679	0.5	0.78	365	45562.39
4A	2	5.934	0.5	0.78	365	1689.41
6A	627	6.003	0.5	0.78	365	535788.5
Total						737297

$$RSL = \frac{\mathbf{737297}}{\mathbf{5288918}} \times \mathbf{15} = \mathbf{2.091}$$

iv. Remaining Service Life for July, Nairobi bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented in Table 4-7 and Table 4-8 respectively.

Table 4-7: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	414	115	0.5	0.78	365	6779584
3A	108	9.743	0.5	0.78	365	149789.6
4A	2	3.497	0.5	0.78	365	995.5035
6A	416	6.675	0.5	0.78	365	395281
Total						7325650

Table 4-8: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	414	3.898	0.5	0.78	365	229720.4
3A	108	3.679	0.5	0.78	365	56560.21
4A	2	5.934	0.5	0.78	365	1689.41
6A	416	6.003	0.5	0.78	365	355483.3
Total						643453.3

$$RSL = \frac{\mathbf{643453.3}}{\mathbf{7325650}} \times \mathbf{15} = \mathbf{1.318}$$

The variations in the values of the remaining service life over the period of study are significant since the error bars show no intense overlapping except for June which has a higher value. This is seen in Figure 4-19 below.

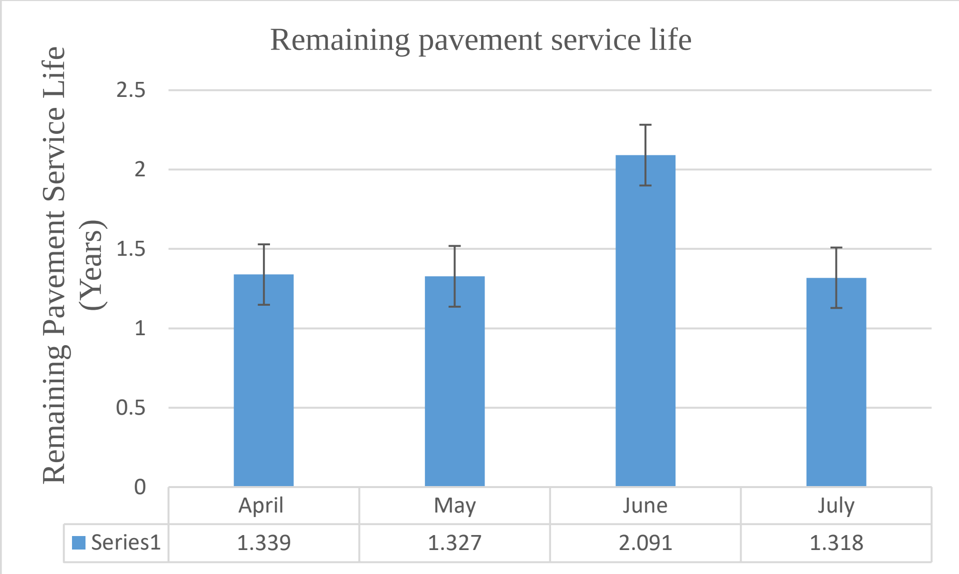


Figure 4-19: Remaining pavement service life from Nairobi bound traffic

The calculations of the remaining service life indicate a percentage reduction in the remaining service life of the pavement as high as 91.21%. A study done by Nath in Nepal revealed that overloading could reduce the service life of a pavement by 59.9% (Ojha, 2018). The pavement destruction caused by the measured overloads is extreme as seen in Figure 4-20. This information can be used to warrant increased traffic regulations enforcement.

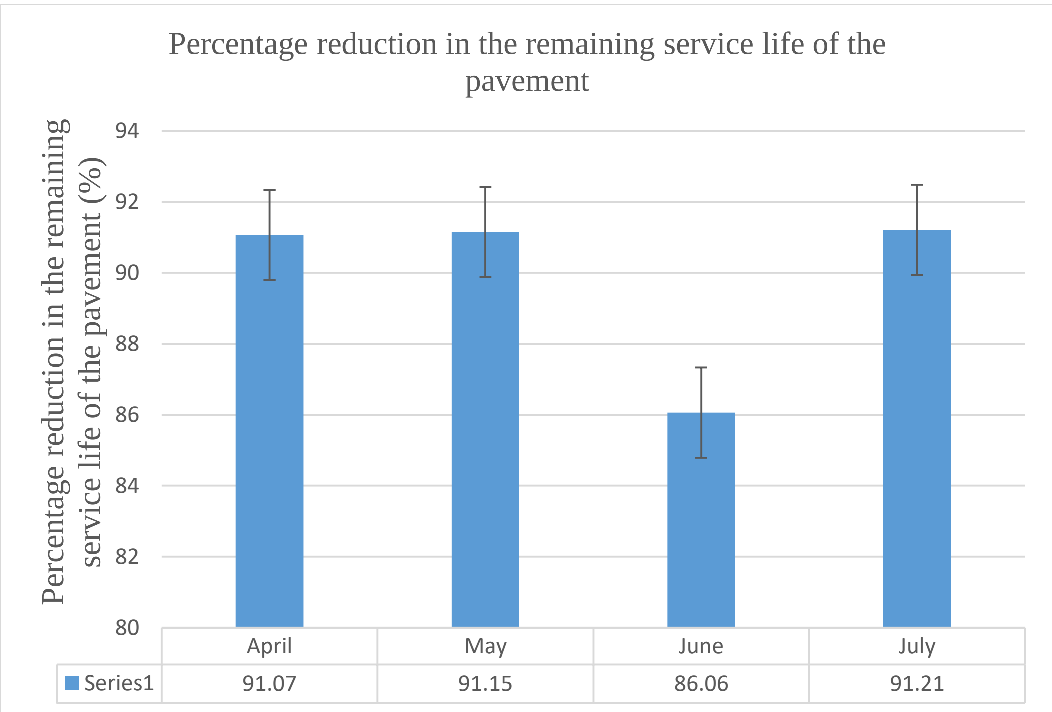


Figure 4-20: Percentage reduction in the remaining service life of the pavement

v. Remaining Service Life for April, Mombasa bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic for April in the Mombasa direction are presented in Table 4-9 and Table 4-10 and respectively.

Table 4-9: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	170	20.78	0.5	0.78	365	503000
3A	139	14.84	0.5	0.78	365	29380
4A	6	2.714	0.5	0.78	365	2318
6A	123	8.706	0.5	0.78	365	152400
Total						952000

Table 4-10: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	170	3.898	0.5	0.78	365	94330
3A	139	3.679	0.5	0.78	365	72795
4A	6	5.934	0.5	0.78	365	5068
6A	123	6.003	0.5	0.78	365	105107
Total						277295

The remaining service life is an estimate of the total number of years that a pavement can be in normal condition both functionally and structurally while undergoing only routine maintenance. Overloading beyond the design traffic loads leads to premature traffic road deterioration causing a reduction in the pavement service life.

$$RSL = \frac{\mathbf{277295}}{\mathbf{952000}} \times \mathbf{15} = \mathbf{4.372}$$

From the RSL calculations, it was found that the pavement with a design period of 15 years if subjected to repetitive loadings of the magnitude used in the calculations, then the remaining pavement service life would be approximately 4 years and 5 months after which it would require major rehabilitation.

vi. Remaining Service Life for May, Mombasa bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented in Table 4-11 and Table 4-12 respectively.

Table 4-11: Estimated traffic in the design life of pavement (overload)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	141	152.2	0.5	0.78	365	3055216
3A	42	9.595	0.5	0.78	365	57364
4A	3	3.436	0.5	0.78	365	1467
6A	118	7.953	0.5	0.78	365	133594
Total						3247641

Table 4-12: Estimated traffic in the design life of pavement (standard)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	141	3.898	0.5	0.78	365	78238.12
3A	42	3.679	0.5	0.78	365	21995.64
4A	3	5.934	0.5	0.78	365	2534.115
6A	118	6.003	0.5	0.78	365	100834.2
Total						203602.1

$$RSL = \frac{\mathbf{203602.1}}{\mathbf{3247641}} \times \mathbf{15 = 0.9404}$$

From the RSL calculations, it was found that the pavement with a design period of 15 years if subjected to repetitive loadings of the magnitude used in the calculations, then the remaining pavement service life would be approximately 11 months after which it would require major rehabilitation.

vii. Remaining Service Life for June, Mombasa bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented in Table 4-13 and Table 4-14 respectively.

Table 4-13: Estimated traffic in the design life of pavement (overload)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	113	170.3	0.5	0.78	365	2739475
3A	86	9.893	0.5	0.78	365	121115.5
4A	3	2.764	0.5	0.78	365	1180.724
6A	114	6.097	0.5	0.78	365	98942.62
Total						2960714

Table 4-14: Estimated traffic in the design life of pavement (standard)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	113	3.898	0.5	0.78	365	62701.47
3A	86	3.679	0.5	0.78	365	45038.69
4A	3	5.934	0.5	0.78	365	2534.115
6A	114	6.003	0.5	0.78	365	97416.08
Total						207690.4

$$RSL = \frac{\mathbf{207690.4}}{\mathbf{2960714}} \times \mathbf{15 = 1.052}$$

From the RSL calculations, it was found that the pavement with a design period of 15 years if subjected to repetitive loadings of the magnitude used in the calculations, then the pavement service life would be reduced to approximately 1 year and 1 month after which it would require major rehabilitation.

viii. Remaining Service Life for July, Mombasa bound Traffic

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented in Table 4-15 and Table 4-16 respectively.

Table 4-15: Estimated traffic in the design life of pavement (overload)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	197	141.7	0.5	0.78	365	3972831
3A	174	9.303	0.5	0.78	365	230422.1
4A	5	5.218	0.5	0.78	365	3714.031
6A	178	7.84	0.5	0.78	365	198659.9
Total						4405627

Table 4-16: Estimated traffic in the design life of pavement (standard)

Vehicle Type	**N_j**	**VDF_j**	**D_D**	**D_L**	**Number of days**	**Design Traffic (CESAL)**
2A	197	3.898	0.5	0.78	365	109311.4
3A	174	3.679	0.5	0.78	365	91124.78
4A	5	5.934	0.5	0.78	365	4223.525
6A	178	6.003	0.5	0.78	365	152105.8
Total						356765.5

$$RSL = \frac{\mathbf{356765.5}}{\mathbf{4405627}} \times \mathbf{15} = \mathbf{1.215}$$

From the RSL calculations, it was found that the pavement with a design period of 15 years if subjected to repetitive loadings of the magnitude used in the calculations, then the pavement service life would be reduced to approximately 1 year and 3 months after which it would require major rehabilitation.

The estimated Remaining Service Life (RSL) of the pavement with Nairobi bound traffic for the four months which the study spanned are indicated in Figure 4-21 with April having the highest RSL value while May having the least. The variations in the remaining service life are significant except for April because the error bars have small overlaps. The value of RSL for April is larger and thus the intense overlapping of the error bar.

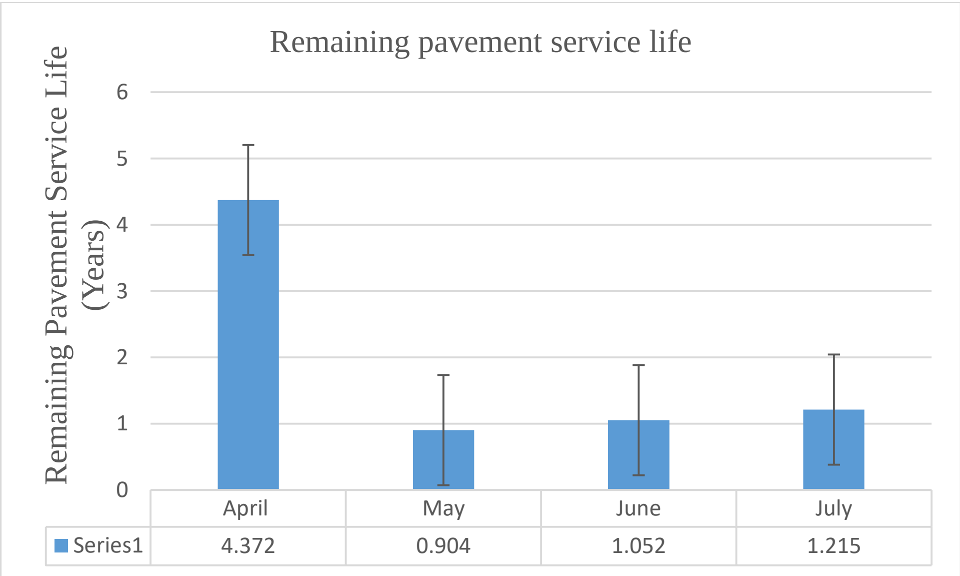


Figure 4-21: Remaining service life of pavement from Mombasa bound traffic direction

The extreme pavement destruction caused by overloaded vehicles can be seen by the high percentage reduction of the service life of the pavement as shown in Figure 4-22. These extremes warrant strict traffic regulations enforcement.

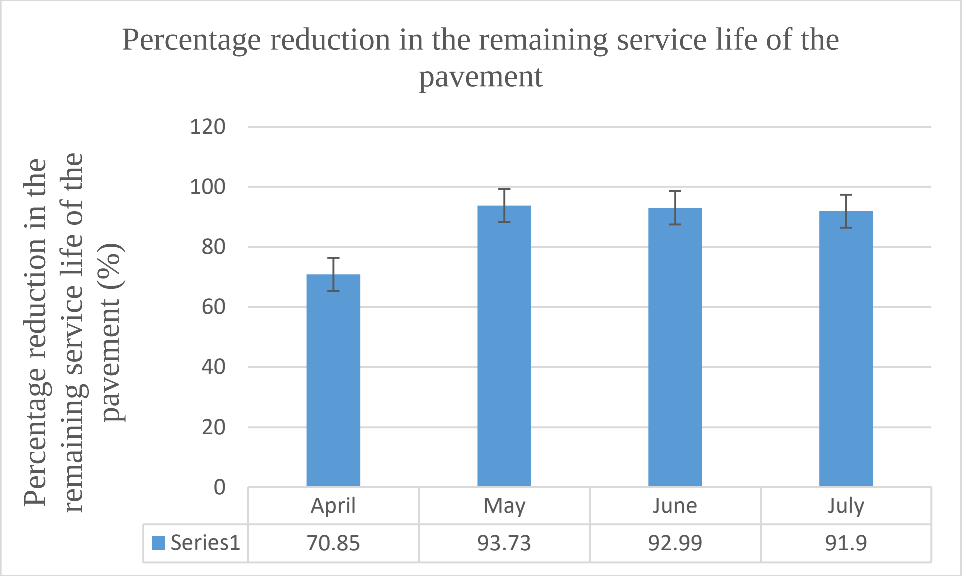


Figure 4-22: Percentage reduction in the service life of the pavement

4.6 Assessing the Pavement Condition by Visual Analysis of the Pavement Along the Section Under Study to Identify Pavement Deterioration.

Overloading is one of the major factors causing pavement failure on the Northern Corridor (Arnold, 2017). Examples of pavement deterioration observed along the Northern corridor Athi River interchange to City Cabanas section include:

i. Cracking is the formation of approximate vertical cleavage of a pavement layer and occurs when the pavement layer breaks along lines of weakness as a result of excess axle loads (Ministry of Roads and Public Works, 1988). The most common types of cracking include fatigue cracking, transverse cracking, longitudinal cracking, and block cracking. Cracking was observed on some sections of the pavement as shown in Plate 4-1.

Plate 4-1: Longitudinal and transverse cracking of pavement surface

Source: Author, 2020

ii. Rutting – This refers to the displacement of pavement materials turning wheel paths into channels. Water starts to accumulate in the rut resulting from the failure of one or more pavement layers and the width of the rut signifies the respective layer that has failed, in which a wide rut shows the failure of the subgrade while a narrow one shows surface failure (Ministry of Roads and Public Works, 1988). Ruts normally occur as a result of excessive loading or inadequate compaction during road construction. On the area under study rutting was observed to have occurred an instance of which is depicted in Plate 4-2.

Plate 4-2: Excessive rutting on pavement surfacing

Source: Author, 2020

iii. Potholes are bowl-shaped formations similar to depressions and occur as a result of progressive failure of the pavement, beginning to form when small fragments are dislodged from the asphalt concrete layer (O'Flaherty, 2007). The distress progresses in the underlying layers of the pavement disintegrating the pavement due to repeated traffic loading. Potholes were observed at different sections of the pavement as shown in Plate 4-3.

Plate 4-3: Miniature pothole

Source: Author, 2020

iv. Corrugation/wash boarding - these are ripples formed laterally across an asphalt pavement surface as shown in Plate 4-4 (Ministry of Roads and Public Works, 1988). Corrugations normally occur at points where vehicles normally accelerate or decelerated and failure in the asphalt concrete layer at such points results from the application of too much asphalt concrete layer during construction that had very fined aggregates and smooth or rounded coarse aggregates

Plate 4-4: Corrugations on the pavement surface

Source: Author, 2020

v. Edge spalling – This is the breaking of pavement at the edge due to a lack of edge support (Al-Arkawazi, 2017) shown in Plate 4-5. This was caused by overloaded trucks that drive on the road shoulder.

Plate 4-5: Plate showing a section that has undergone edge spalling

Source: Author, 2020

vi. Bleeding - the appearance of asphalt binder on the surface of the pavement seen in Plate 4-6 (Ministry of Roads and Public Works, 1988). When a pavement is subjected to excessive loads, the asphalt binder may be extruded to the surface as the voids in the pavement structure are filled due to excessive compaction by the loads.

Plate 4-6: Bleeding of the asphaltic binder

Source: Author, 2020

vii. Shoving - Shoving is a form of localized bulging of the pavement that occurs as a result of plastic movement in the asphalt concrete layer (O'Flaherty, 2007). Overloading especially where the subgrade is weak causes shoving. At a section of the pavement under study, shoving occurred repeatedly leading to the eventual total replacement of the section with a rigid pavement shown in Plate 4-7.

Plate 4-7: Section replaced with a rigid pavement due to repeated shoving.

Source: Author, 2020

4.7 Questionnaire Data Collection and Analysis

As part of the study, questionnaires were administered to transporters. The questionnaire data was collected at Athi River (Mlolongo Weighbridge). The questionnaires were administered to long and short distance drivers from Mombasa and Nairobi bound traffic at the weighbridge. The axle configuration of vehicles was also varied. This was to get results covering as many variations in traffic as possible.

4.7.1 Transporters Awareness of Axle Load Limits and Their Views on Overloading

This section provides a summary and analysis of key data obtained from the survey on the various survey questions.

The transporters were assessed on their level of awareness on legal gross weights of vehicles. The data from the questionnaire is presented in Figure 4-23.

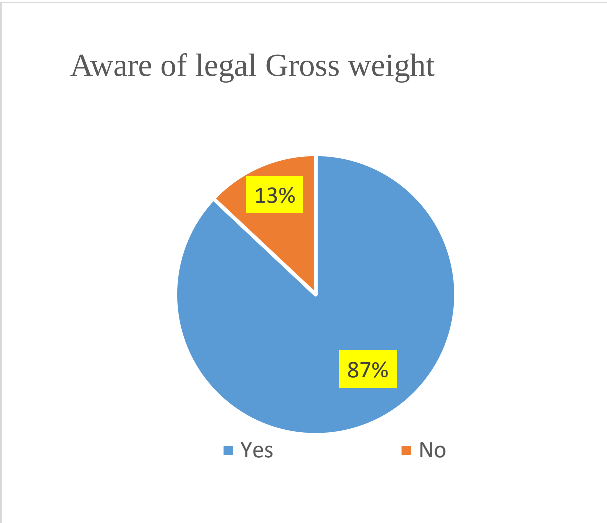


Figure 4-23: Level of awareness about the legal gross vehicle weight

87% of the interviewed drivers were aware of the legal gross weight as shown in Figure 4-23. A significant percent of the interviewed drivers was not aware of the allowable gross vehicle weights. This finding can be used to warrant education programmes that aim at raising the drivers' awareness about the allowable loading limits. Interviews conducted by Janet Rop in 2019 to identify reasons why sand truck drivers were persistently overloading along the Kajiado – Isara road revealed that most drivers were not aware of the axle load limits set by the road management officials. Road management agencies should conduct mass education about the legal gross weight and axle load limits of freight vehicles to avoid cases of overloading due to ignorance about vehicle loading limits.

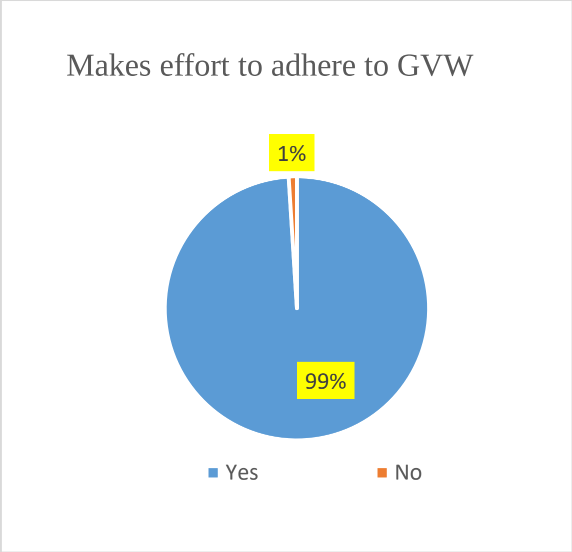


Figure 4-24: Level of compliance with the loading limits

Of the drivers interviewed for the questionnaire, 99% of the drivers made an effort to adhere to the axle load limits as seen in Figure 4-24. This shows a willingness of transporters to adhere to regulations. It is therefore possible to curb overloading by ensuring drivers are aware of axle load limits and other loading regulations as they showed a willingness to adhere to them. The non-compliant drivers contribute to the premature deterioration of the pavement when they overload their vehicles past the allowable loading limits. They can be identified and measures to discourage repeated offending taken against them.

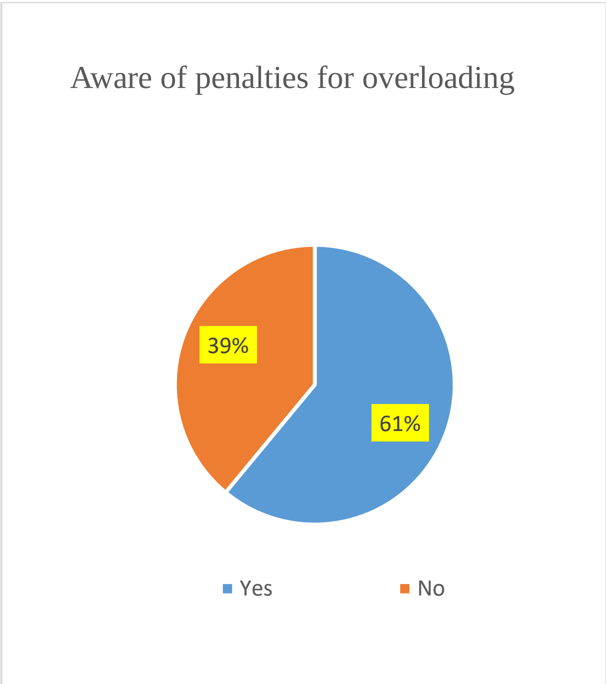


Figure 4-25: Level of awareness about the overloading penalties

61% of the interviewed truck drivers were aware of the overloading penalties. A significant number of the drivers had no clue about the sanctions and fines that are associated with overloading as shown in Figure 4-25. These drivers need to be informed and educated about the disadvantages of overloading. This way, they can help to preserve the service life of the pavement and they can save themselves from a financial crisis due to overloading fines

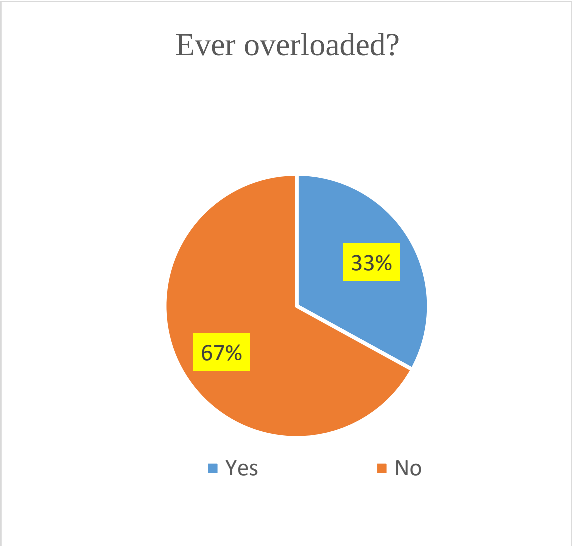


Figure 4-26: Percentage of drivers who had overloaded before

33% of the interviewed drivers had overloaded before. Most of the interviewed drivers were law-abiding as seen in Figure 4-26. Vehicles within the legal gross weight do not cause excessive distress on the pavement. Pavements with overloaded vehicles often require expensive unplanned maintenance. Drivers should be educated about the dangers of overloading so that they can avoid overloading.

The age group distribution of transporters was assessed and the data presented in Figure 4-27 below.

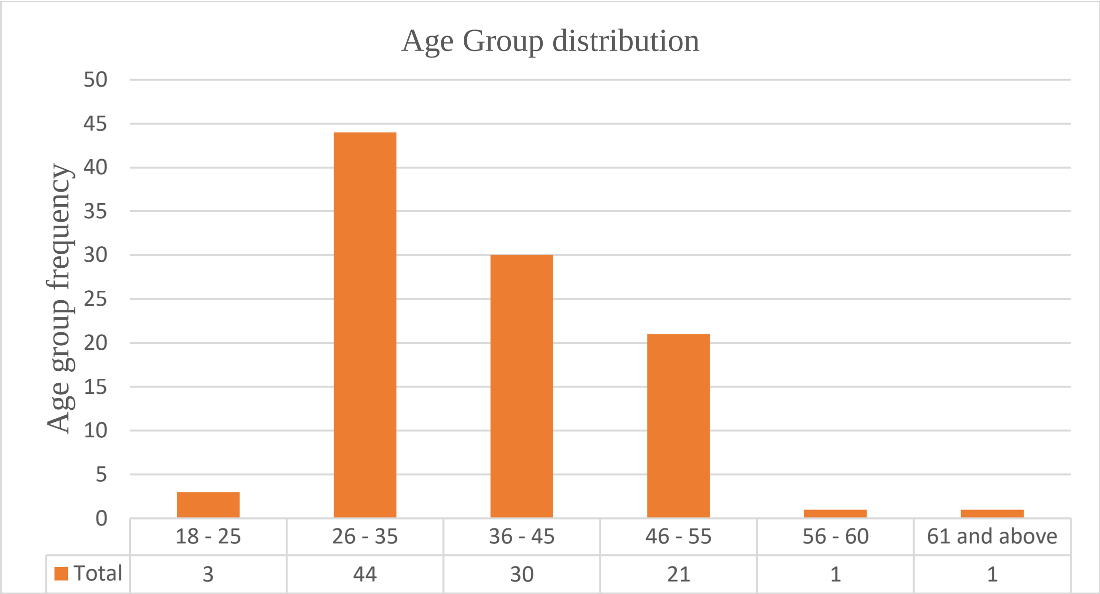


Figure 4-27: Age Group distribution

Age of transporters and drivers is important when it comes to road use. Age often relates to experience with most transporters starting out at a relatively young age. Experience leads to a higher awareness of axle load limits and loading regulations since the driver will be exposed many times to weighbridges and its operations. From the sampled group, the age group with most number of transporters was 26-35 years. The number of respondents sampled then reduced with age. This can be attributed to the amount of work transporters do. Most are required to work long hours, drive long distances and handle heavy loads. This makes the work less attractive as transporters age. Working conditions should be improved in the transportation business so as to improve labour retention. A higher number of older drivers with more experience may increase adherence rates to the GVW and axle load limits as the levels of awareness would improve with awareness.

Employer guidelines on loading and axle load regulation – Out of the truckers interviewed, 91% worked for companies with guidelines on loading and axle load regulations. Several of the employers provided weigh stations at loading points to ensure compliance with the set load limits. The challenge cited by drivers is that the private weigh stations mostly measure total gross vehicle weight. This leads to improper load distribution between the axles. Drivers with overloaded axles are forced to stop at the weighbridge and redistribute load to comply with individual axle limits. Drivers carrying perishables and loads that cannot be redistributed such as fluids are forced to pay a stiff fine.

From the open-ended questions:

i. Some drivers expressed concern over inconsistencies in weighbridges. They were cleared at previous weighbridges only to be found at fault at other weighbridges.

ii. Sand transport drivers had no way of verifying load as they use visual estimation that is highly unreliable and varies with sand moisture content. They, therefore, asked for the provision of a weighbridge at the sand loading points for load verification.

iii. Drivers expressed frustration because some employers made them liable for overloading charges even when they took no part in the loading itself.

iv. Some drivers claimed to have verified Gross Vehicle Weight before transit began only to be found at fault at the weighbridges. This creates mistrust and the drivers felt they would be more comfortable with a more automated system.

v. Some drivers felt that the charges imposed on overloading were too high.

vi. A few of the drivers understood the importance of axle load limits in protecting the loads and were positive about them.

4.7.2 Reasons for Continued Overloading Despite Measures to Curb Overloading

From the traffic loading trends observed at weighbridges, overloading still happens despite the measures and stiff penalties in place to curb the same. The interviewed truck drivers gave additional comments that shed light on the reasons for continued overloading despite stringent measures. Some of the contributing factors to the continued overloading are:

i. One of the major reasons for continued overloading on the route under study, especially among sand and local drivers is the availability of alternative routes. Local drivers are well aware of routes to use to avoid the static weighbridges. They take advantage of these routes and overload knowing that they will avoid detection. A small percentage of the drivers are arrested by the mobile weighbridge. This however doesn’t discourage the drivers from using the routes as they are willing to risk overloading for profit as there’s only a small chance that they will get caught.

ii. Another reason for the continued overloading is the lack of knowledge among truck drivers on the proper load limits and the penalties. Out of the drivers interviewed, 87% said they were aware of the gross vehicle weight limits. 61% of the drivers said they were aware of the penalties. Even among the drivers who claimed to be aware, there was a lack of adequate knowledge with most having only a vague understanding. This might have led to drivers overloading from ignorance and hence causing continued overloading as they aren't even aware of the stringent policies put in place.

iii. A majority of the transporters especially those carrying sand have no means of load verification instead relying on visual estimation. This method is unreliable particularly for sand transport as weight greatly varies depending on the moisture content. This lack of a proper way to verify load leads to truck drivers inadvertently overloading despite being aware of load limits and trying to adhere to them.

iv. Another major overloading reason was found to be overloading among the individual axles. Vehicles were found to comply with the vehicle gross weight limit but had overloaded individual axles. This might be due to poor body design and axle configuration in trucks. This might also be due to poor load fastening after loading leading to shifts during transit. This poor load distribution leads to road destruction by overloaded axles as they exceed individual axle load limits. We can therefore bring in truck manufactures on board so as to review truck axle and body designs.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this study was to evaluate the loading trends on the Northern corridor, Athi River to City Cabanas section and to quantitatively assess the impact of overloading on pavement life in terms of remaining service life.

From the study, Mombasa bound traffic was found to have its lowest overload rate of 23.64% recorded in May and the highest overload of 33.64% recorded in July. Nairobi bound traffic had its lowest overload rate as 11.45% recorded in April and its highest overload as 16.94% recorded in May. The large difference in overloads was attributed to the fact that Nairobi bound traffic that originated from the Mombasa passed through the Mariakani weighbridge where overloads were detected and corrected. The overloads in the Nairobi bound traffic may have been from traffic originating past the Mariakani weighbridge. This shows the effectiveness of weighbridges as a measure to control overloading. More weighbridges should be therefore installed on major roads and at reasonable intervals to control overloading therefore preventing road deterioration due to overloading.

Comparing individual axle overloading rates for Nairobi bound traffic, for the 2A configuration, axle 1 was found to have a very low rate of overloading with its highest being 0.6% in July. Axle 2 for the 2A configuration was found to have a high overload rate the highest being 96.54% in June and the lowest being 85.78% in July. Similarly, the overload rates among various axles for 3A was found to vary widely with the front axle having its highest overload rate as 7.01% and the highest for the rear axle being 88.56%. The large difference in overloading may have been due to poor vehicle fabrication causing uneven load distribution among the axles. Overloading of individual axles even when the vehicle is below the legal gross vehicle weight leads to pavement deterioration. The load distribution for the 4A configuration among the various axle groups was found to vary slightly. The highest overloading rate for the front axle was 71.69% and the highest overloading rate for the rear axle group was 82.22%.

For the Mombasa bound traffic, individual axle overloads were found to follow a similar pattern as for the Nairobi bound traffic. For the 2A configuration, axle 1 had a very low rate of overloading with its highest being 0.71%. Axle 2 for the 2A configuration was found to have a high overload rate the highest being 87.67%. The overload rates among various axles for 3A were found to vary widely with the front axle having its highest overload rate as 11.39% and the highest for the rear axle group being 91.51%. This large difference in overloading may have been due to poor vehicle fabrication causing uneven load distribution among the axles. The load distribution for the 4A configuration among the various axle groups did not vary as much as that of the 2A and 3A configurations and can be considered reasonable. The highest overloading rate for the front axle was 44.83% and the highest overloading rate for the rear axle group was 86.62%.

The overload rates for vehicles weighed by the static weighbridge were found to range between 7.99% - 10.3% as seen in Figure 4-2. While the overload rates for vehicles weighed by the mobile weighbridge ranged between 59% - 83%. The mobile unit was designed to weigh vehicles that might have not passed through the weighbridge either because they intentionally tried to escape the weighbridge or because the traffic originated past the weighbridge. Comparing the overload rates, it is clear that the vehicles not passing by the weighbridge tended to be overloaded as compared to those that did. It is therefore important to increase on mobile weighbridge operations to capture the vehicles that overload and don’t pass through the static weighbridge.

Overloading is the chief contributor to pavement deterioration. Based on the estimates for the remaining service life in section 4.5 it is found that overloading reduces pavement service life. For Nairobi bound traffic, the remaining service life from a design life of 15 years was estimated to be between 1.318 and 2.091 years while for remaining service life due to Mombasa bound traffic was found to range between 0.904 and 4.372. These figures represent a huge reduction in pavement life of even up to 93.73% in May. Based on these findings, the impact of overloading on pavement service life is indisputable. Measures to curb overloading should therefore be implemented strictly if the pavement design life is to be attained.

From visual analysis of the pavement, pavement deterioration was identified along the section. Rutting was identified on the pavement along the section under study.

Based on the questionnaire survey, 13% of the transporters were not aware of the vehicle gross weight limits. 39% of truck drivers were found not to be aware of the overloading penalties which reduces the effectiveness of the penalties as a deterrence. From the drivers that were interview, 99% were found to make an effort to adhere to the loading limits. Based on their willingness to adhere to regulations, awareness on load limits, penalties and other regulations was identified as the largest gap when it comes to adherence to loading limits.

The State Department of Transport and infrastructure guided by the Kenya National Highways Authority has taken into its mandate to ensure the installation of weighbridges along the major roads to curb this menace. Researchers are also continuing to find ways to combat the overloading problem. Based on findings of this study better solutions to overloading can be developed and resources spent due to overloading on roads better used. More research and innovation are needed to maintain our roads, while still supporting the truck business since it also plays a major role in our economy.

5.2 Recommendations

5.2.1 Recommendations from this Study

Based on the traffic loading trends, impact of loading on pavement life and questionnaire findings, the following recommendations were developed following the aims of the study:

i. Based on the loading trends, it was found that there was a large difference in overloading between Mombasa bound traffic and Nairobi bound traffic with Nairobi bound traffic being having less overloading rates. This can be attributed to the existence of the weighbridge at Mariakani where traffic from Mombasa passes through and overloads are detected. Weighbridges are therefore an effective tool to curb overloading and should therefore be deployed in more sections of the major transport corridors

ii. From the data on estimation of remaining service life, it was found that overloading had a very adverse effect on pavement life with reductions even greater than 90% of design life. It is therefore important that strict measures to curb overloading such as steeper fines for overloading are taken to preserve the pavement.

iii. From the mobile weighbridge data, it was found that most of the trucks that were captured overloading by the mobile unit were sand trucks. The drivers are mostly local and aware of alternative routes to avoid the static weighbridge. This intentional avoidance of the weighbridge may be due to an intentional overload for profit. To curb this, stricter penalties should be introduced especially for repeat offenders. More mobile weighbridge units should be deployed along the alternative routes. This will discourage overloading and the use of alternative routes as the chances of getting caught will increase.

iv. Relevant government authority bodies through transport and logistics companies should conduct mass education programs to educate and inform their transporters on the effects of overloading, loading limits and penalties of overloading. The employees should also be notified of any policy changes through their respective companies. From the questionnaire data, it was found that the majority of drivers who were aware made a conscious effort to adhere to the regulations. Increased awareness will therefore help curb overloading on the roads.

v. SACCOs and transport companies should provide mobile weighing stations at loading points such as sand weighing points to verify the Gross Vehicle Weight before transit begins to help in compliance with axle load limits.

vi. From overloading data among various axles, it was found that some axles were severely overloaded as compared to the rest of the axles. This might be due to poor vehicle fabrication leading to improper weight distribution among the axles. The relevant government agencies in conjunction with truck manufactures should come up with better guidelines and regulations for truck body designs and axle configuration. This will ensure proper load distribution between the various axles and hence prevent individual axle overloads. Transporters should also be encouraged to brace and fasten cargo properly before transit begins to prevent shifting of previously well-distributed load.

5.2.2 Recommendations for Further Research

i. Evaluation of the financial impact of overloading in terms of road maintenance and rehabilitation costs - The equivalent single axle loads (ESAL) approach which uses the ‘fourth-power rule’ to quantify the damaging effect of overloaded vehicles can be used to determine the cost-benefit ratio of pavement infrastructure (Jacob, 2020). Aggregated data from KeNHA about the maintenance and rehabilitation cost of the Northern corridor has been presented in the literature review. However, the impact of overloaded vehicles on the maintenance cost has not been clearly discussed as the cost data that was available did not isolate the specific impact of overloaded vehicles with relation to maintenance costs. The benefits (in monetary value) realized from a road asset can be divided by the cash outflow resulting from road asset maintenance to get the cost-benefit ratio of the road project. This ratio can be calculated for different periods to compare the ratios found with respect to the trends in vehicle loading for the specific periods. During periods with high overloading cases, it is expected that the ratio will be low and vice versa. For this to be proved, this study recommends further research on the financial impact of overloading in terms of road maintenance and rehabilitation costs.

ii. Modelling of pavement response using locally available materials that improve the pavement layers' resilient moduli - Overweight vehicles have been proved to cause excessive distress on the pavement which leads to the reduction in the service life of the pavement. To counteract these excessive loads, studies have recommended that the pavement layer thicknesses and the pavement material resilient moduli should be modified (Pengfei Liu & Dawei Wang, 2017). The pavements can be strengthened using materials such as SAMI or reinforcement bars. For optimum strengthening, pavement modelling under different loadings has to be conducted. This simulation can be very costly due to the expensive nature of the reinforcing materials. This study recommends further investigation of locally available materials such as littered plastics that are rich in polymer which can be used as stabilizing agents or additives to aggregate blends in flexible pavements.
iii. Research into the use of rigid pavement for trunk roads – A majority of roads in Kenya are flexible pavements. Rigid pavements have been found to have less maintenance costs despite the higher initial costs. They perform well under heavy load. For the James Gichuru – Rironi Highway that is nearing completion, a composite pavement has been adopted where the left hand side of the road from Gitaru near Kikuyu is a rigid pavement while the right hand side is a flexible pavement. The left hand side experiences heavily loaded traffic going to the western region of the country where it enters other neighbouring countries. Traffic on the right hand side is less loaded in comparison it is so designed since the heavy traffic originating from the Southern Bypass joins the highway at Gitaru. The perfomance of the rigid pavement over time should be monitored and data of its perfomance over time under local conditions generated. This will guide future adoption of rigid pavements in trunk road construction as this type of road has been found to need less maintenance.
iv. From previous research, geo-synthetic material has been found to improve the service life of the pavement (Teklu, 2016). The material improves fatigue and rut resistance of the pavement. Further research should be carried out locally to test the performance of the material which can then be integrated into designs for heavy traffic if found suitable for local use.

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APPENDICES

Appendix 1: Traffic Data Summary per Month per Axle

Table A1- 1: Axle Loading Summary for Mombasa Bound Traffic in April (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of Overloads	Total Axles	No of Overloads	Total axles	No of Overloads	Total axles	No of Overloads
11989	515	11989	7732	4205	2499	63	0
Axle 1 percentage overload 4.30		Axle 2 percentage overload 64.51		Axle 3 percentage overload 59.43		Axle 4 percentage overload 0	

Table A1- 2: Axle Loading Summary for Nairobi Bound Traffic in April (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of overloads	Total axles	No of overloads	Total axles	No of overloads	Total overloads	No of overloads
30408	646	30408	16398	17127	11269	173	0
Axle 1 percentage overload 2.12		Axle 2 percentage overload 53.93		Axle 3 percentage overload 65.80		Axle 4 percentage overload 0	

Table A1- 3: Axle Loading Summary for Mombasa Bound Traffic in May (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of overload	Total axles	No of overloads	Total axles	No of overload	Total axles	No of overload
13758	602	13758	9350	4226	2443	60	0
Axle 1 percentage overload 4.38		Axle 2 percentage overload 68.02		Axle 3 percentage overload 57.81		Axle 4 percentage overload 0	

Table A1- 4: Axle Loading Summary for Nairobi Bound Traffic in May (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of Overloads	Total Axles	No of Overloads	Total axles	No of Overloads	Total axles	No of Overloads
31649	671	31649	18487	15910	10771	159	0
Axle 1 percentage overload 2.12		Axle 2 percentage overload 58.41		Axle 3 percentage overload 67.70		Axle 4 percentage overload 0	

Table A1- 5: Axle Loading Summary for Mombasa Bound Traffic in June (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of Overloads	Total Axles	No of Overloads	Total axles	No of Overloads	Total axles	No of Overloads
12484	468.00	12482	8501.00	3890	2242.00	47	0.00
Axle 1 percentage overload 3.75		Axle 2 percentage overload 68.14		Axle 3 percentage overload 57.63		Axle 4 percentage overload 0.00	

Table A1- 6: Axle Loading Summary for Nairobi Bound Traffic in June (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of overloads	Total axles	No of overloads	Total axles	No of overloads	Total axles	No of overloads
26531	605	26531	15932	12402	8333	158	0
Axle 1 percentage overload 2.28		Axle 2 percentage overload 60.05		Axle 3 percentage overload 67.19		Axle 4 percentage overload 0	

Table A1- 7: Axle Loading Summary for Mombasa Bound Traffic in July (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of overloads	Total axles	No of overloads	Total axles	No of overload	Total axles	No of overload
16042	0	16042	11300	4472	2256	82	0
Axle 1percentage overload 0		Axle 2 percentage overload 70.54		Axle 3 percentage overload 50.45		Axle 4 percentage overload 0	

Table A1- 8: Axle Loading Summary for Nairobi Bound Traffic in July (2020)

Axle 1		Axle 2		Axle 3		Axle 4	
Total axles	No of overload	Total axles	No of overload	Total axles	No of overload	Total axles	No of overload
36926	890	36926	20723	18293	12229	297	0
Axle 1 percentage overload 2.410		Axle 2 percentage overload 56.14		Axle 3 percentage overload 66.85		Axle 4 percentage overload 0	

Appendix 2: Traffic Loading Data Summary for Each Configuration

Table A2- 1: Axle Loading for 2A configuration for Nairobi Bound Traffic in July (2020)

July Nairobi Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
13790	81	13790	11572
Percentage Overload = 0.60%		Percentage Overload = 85.78%	

Table A2- 2: Axle Loading for 3A configuration for Nairobi Bound Traffic in July (2020)

July Nairobi Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4963	259	4963	4187
Percentage Overload = 5.22%		Percentage Overload = 84.35%	

Table A2- 3: Axle Loading for 4A configuration for Nairobi Bound Traffic in July (2020)

July Nairobi Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
219	138	219	163
Percentage Overload = 63.01%		Percentage Overload = 74.43%	

Table A2- 4: Axle Loading for 6A configuration for Nairobi Bound Traffic in July (2020)

July Nairobi Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
17972	322	17972	4974	17972	12284	17972	0
Percentage Overload = 1.79%		Percentage Overload = 27.68%		Percentage Overload = 68.35%		Percentage Overload = 0%	

Table A2- 5: Axle Loading for 2A configuration for Nairobi Bound Traffic in April (2020)

April Nairobi Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
10596	50	10596	9193
Percentage Overload = 0.47%		Percentage Overload = 86.77%	

Table A2- 6: Axle Loading for 3A configuration for Nairobi Bound Traffic in April (2020)

April Nairobi Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
2549	179	2549	2058
Percentage Overload = 7.01%		Percentage Overload = 80.71%	

Table A2- 7: Axle Loading for 4A configuration for Nairobi Bound Traffic in April (2020)

April Nairobi Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
159	114	159	127
Percentage Overload = 71.69%		Percentage Overload = 79.87%	

Table A2- 8: Axle Loading for 6A configuration for Nairobi Bound Traffic in April (2020)

April Nairobi Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
16883	250	16883	5148	16883	11328	16883	0
Percentage Overload = 1.48%		Percentage Overload = 30.49%		Percentage Overload = 67.10%		Percentage Overload = 0%	

Table A2- 9: Axle Loading for 2A configuration for Nairobi Bound Traffic in May (2020)

May Nairobi Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
11519	50	11519	11572
Percentage Overload = 0.43%		Percentage Overload = 87.05%	

Table A2- 10: Axle Loading for 3A configuration for Nairobi Bound Traffic in May (2020)

May Nairobi Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4098	185	4098	3630
Percentage Overload = 4.51%		Percentage Overload = 88.56%	

Table A2- 11: Axle Loading for 4A configuration for Nairobi Bound Traffic in May (2020)

May Nairobi Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
154	100	116	116
Percentage Overload = 65.36%		Percentage Overload = 75.82%	

Table A2- 12: Axle Loading for 6A configuration for Nairobi Bound Traffic in May (2020)

May Nairobi Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
15719	294	15719	4859	15719	10798	15719	0
Percentage Overload = 1.87%		Percentage Overload = 31.14%		Percentage Overload = 68.69%		Percentage Overload = 0%	

Table A2- 13: Axle Loading for 2A configuration for Nairobi Bound Traffic in June (2020)

June Nairobi Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
10695	47	10695	10324
Percentage Overload = 0.44%		Percentage Overload = 96.54%	

Table A2- 14: Axle Loading for 3A configuration for Nairobi Bound Traffic in June (2020)

June Nairobi Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
3330	174	3330	2871
Percentage Overload = 5.23%		Percentage Overload = 86.22%	

Table A2- 15: Axle Loading for 4A configuration for Nairobi Bound Traffic in June (2020)

June Nairobi Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
135	87	135	111
Percentage Overload = 64.44%		Percentage Overload = 82.22%	

Table A2- 16: Axle Loading for 6A configuration for Nairobi Bound Traffic in June (2020)

June Nairobi Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
12215	257	12215	3678	12215	8342	12215	0
Percentage Overload = 2.10%		Percentage Overload = 30.12%		Percentage Overload = 68.29%		Percentage Overload = 0%	

Table A2- 17: Axle Loading for 2A configuration for Mombasa Bound Traffic, April (2020)

April Mombasa Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4868	27	4868	4245
Percentage Overload = 0.55%		Percentage Overload = 87.20%	

Table A2- 18: Axle Loading for 3A configuration for Mombasa Bound Traffic, April (2020)

April Mombasa Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
2871	327	2871	2487
Percentage Overload = 11.39%		Percentage Overload = 86.62%	

Table A2- 19: Axle Loading for 3A configuration for Mombasa Bound Traffic, April (2020)

April Mombasa Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
49	16	49	32
Percentage Overload = 32.65%		Percentage Overload = 65.31%	

Table A2- 20: Axle Loading for 6A configuration for Mombasa Bound Traffic, April (2020)

April Mombasa Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4069	108	4069	963	4069	2495	4069	0
Percentage Overload = 2.65%		Percentage Overload = 23.67%		Percentage Overload = 61.32%		Percentage Overload = 0%	

Table A2- 21: Axle Loading for 2A configuration for Mombasa Bound Traffic in May (2020)

May Mombasa Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
5074	36	5074	4286
Percentage Overload = 0.71%		Percentage Overload = 84.47%	

Table A2- 22: Axle Loading for 3A configuration for Mombasa Bound Traffic in May (2020)

May Mombasa Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4392	396	4392	3993
Percentage Overload = 9.02%		Percentage Overload = 90.92%	

Table A2- 23: Axle Loading for 4A configuration for Mombasa Bound Traffic in May (2020)

May Mombasa Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
58	26	58	48
Percentage Overload = 44.83%		Percentage Overload = 82.76%	

Table A2- 24: Axle Loading for 6A configuration for Mombasa Bound Traffic in May (2020)

May Mombasa Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4066	95	4066	1011	4066	2439	4069	0
Percentage Overload = 2.34%		Percentage Overload = 24.86%		Percentage Overload = 59.99%		Percentage Overload = 0%	

Table A2- 25: Axle Loading for 2A configuration for Mombasa Bound Traffic in June (2020)

June Mombasa Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4900	35	4900	4296
Percentage Overload = 0.71%		Percentage Overload = 87.67%	

Table A2- 26: Axle Loading for 3A configuration for Mombasa Bound Traffic in June (2020)

June Mombasa Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
3638	267	3638	3329
Percentage Overload = 7.34%		Percentage Overload = 91.51%	

Table A2- 27: Axle Loading for 4A configuration for Mombasa Bound Traffic in June (2020)

June Mombasa Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
61	26	61	50
Percentage Overload = 42.62%		Percentage Overload = 81.97%	

Table A2- 28: Axle Loading for 6A configuration for Mombasa Bound Traffic in June (2020)

June Mombasa Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
3702	91	3702	822	3702	2226	3702	0
Percentage Overload = 2.46%		Percentage Overload = 22.20%		Percentage Overload = 60.13%		Percentage Overload = 0%	

Table A2- 29: Axle Loading for 2A configuration for Mombasa Bound Traffic in July (2020)

July Mombasa Bound			
2A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
5733	37	5733	4996
Percentage Overload = 0.65%		Percentage Overload = 87.14%	

Table A2- 30: Axle Loading for 3A configuration for Mombasa Bound Traffic in July (2020)

July Mombasa Bound			
3A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
5730	443	5730	5176
Percentage Overload = 7.73%		Percentage Overload = 90.33%	

Table A2- 31: Axle Loading for 4A configuration for Mombasa Bound Traffic in July (2020)

July Mombasa Bound			
4A Configuration			
Axle 1		**Axle 2**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
127	52	127	103
Percentage Overload = 40.94%		Percentage Overload = 81.10%	

Table A2- 32: Axle Loading for 6A configuration for Mombasa Bound Traffic in July (2020)

July Mombasa Bound							
6A Configuration							
Axle 1		**Axle 2**		**Axle 3**		**Axle 4**	
Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles	Total Axles	Overloaded Axles
4296	90	4296	1018	4296	2248	4296	0
Percentage Overload = 2.09%		Percentage Overload = 23.70%		Percentage Overload = 52.32%		Percentage Overload = 0%	

Appendix 3: Calculation of The Remaining Service Life

The detailed calculations for remaining service life are as follows:

Assumptions:

i. Assume the road is opened to traffic on the day of traffic count.
ii. Take the pavement service life to be 15 years.
iii. Consider the most severe axle load for each class of vehicle

i. Mombasa Bound Traffic

Taking the 2A configuration in the month of April for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 170 (Number of Mombasa bound 2A vehicles counted on the first day of April)

K = 1

Q_i = 17080 Kg = 170.8 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{170.8}{80}\right)^4 = 20.78$$

$$CESAL = 170 \times 20.78 \times 0.5 \times 0.78 \times 365 = 503\, x\, 10^3$$

Taking the 3A configuration in the month of April for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 139 (Number of Mombasa bound 3A counted on the first day of April)

K = 0.086

Q_i = 29000 Kg = 290 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{290}{80}\right)^4 = 14.85$$

$$CESAL = 139 \times 1.485 \times 0.5 \times 0.78 \times 365 = 293.8\, x\;\; 10^3$$

Taking the 4A configuration in April for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 6 (Number of Mombasa bound 4A vehicles counted on the first day of April)

K = 0.053

Q_i = 21400 Kg = 214 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{214}{80}\right)^4 = 2.714$$

$$CESAL = 6 \times 2.714 \times 0.5 \times 0.78 \times 365 = 2.318 \times 10^3$$

Taking the 6A configuration in April for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 123 (Number of Mombasa bound 6A vehicles counted on the first day of April)

K = 0.053

Q_i = 28640 Kg = 286.4 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{286.4}{80}\right)^4 = 8.706$$

$$CESAL = 123 \times 8.706 \times 0.5 \times 0.78 \times 365 = 152.4\, x\, 10^3$$

Table A3- 1: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	170	20.78	0.5	0.78	365	503000
3A	139	14.84	0.5	0.78	365	29380
4A	6	2.714	0.5	0.78	365	2318
6A	123	8.706	0.5	0.78	365	152400
Total						952000

Table A3- 2: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	170	3.898	0.5	0.78	365	94330
3A	139	3.679	0.5	0.78	365	72795
4A	6	5.934	0.5	0.78	365	5068
6A	123	6.003	0.5	0.78	365	105107
Total						277295

$$RSL = \frac{\mathbf{277295}}{\mathbf{952000}} \times \mathbf{15} = \mathbf{4.372}$$

Taking the 2A configuration in the month of May for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 141 (Number of Mombasa bound 2A vehicles counted on the first day of May)

K = 1

Q_i = 28100 Kg = 281 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{281}{80}\right)^4 = 152.2$$

$$CESAL = 141 \times 281 \times 0.5 \times 0.78 \times 365 = 3055.2\ x\ 10^3$$

Taking the 3A configuration in the month of May for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 42 (Number of Mombasa bound 3A counted on the first day of May)

K = 0.086

Q_i = 26000 Kg = 260 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{260}{80}\right)^4 = 9.595$$

$$CESAL = 42 \times 9.595 \times 0.5 \times 0.78 \times 365 = 57.36\,x\ \ 10^3$$

Taking the 4A configuration in May for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 3 (Number of Mombasa bound 4A vehicles counted on the first day of May)

K = 0.053

Q_i = 22700 Kg = 227 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{227}{80}\right)^4 = 3.435$$

$$CESAL = 3 \times 3.435 \times 0.5 \times 0.78 \times 365 = 1.467 \times 10^3$$

Taking the 6A configuration in May for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 118 (Number of Mombasa bound 6A vehicles counted on the first day of May)

K = 0.053

Q_i = 28000 Kg = 280 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{280}{80}\right)^4 = 7.953$$

$$CESAL = 118 \times 7.953 \times 0.5 \times 0.78 \times 365 = 134\,x\,10^3$$

Table A3- 3: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	141	152.2	0.5	0.78	365	3055216
3A	42	9.595	0.5	0.78	365	57364
4A	3	3.436	0.5	0.78	365	1467
6A	118	7.953	0.5	0.78	365	133594
Total						3247641

Table A3- 4: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	141	3.898	0.5	0.78	365	78238.12
3A	42	3.679	0.5	0.78	365	21995.64
4A	3	5.934	0.5	0.78	365	2534.115
6A	118	6.003	0.5	0.78	365	100834.2
Total						203602.1

$$RSL = \frac{\mathbf{203602.1}}{\mathbf{3247641}} \times \mathbf{15} = \mathbf{0.9404}$$

Taking the 2A configuration in the month of June for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 113 (Number of Mombasa bound 2A vehicles counted on the first day of June)

K = 1

Q_i = 28900 Kg = 289 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{289}{80}\right)^4 = 170.3$$

$$CESAL = 113 \times 289 \times 0.5 \times 0.78 \times 365 = 2739.5\ x\ 10^3$$

Taking the 3A configuration in the month of June for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 86 (Number of Mombasa bound 3A counted on the first day of June)

K = 0.086

Q_i = 26200 Kg = 262 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{262}{80}\right)^4 = 9.893$$

$$CESAL = 86 \times 9.893 \times 0.5 \times 0.78 \times 365 = 121.1\, x \;\; 10^3$$

Taking the 4A configuration in June for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 3 (Number of Mombasa bound 4A vehicles counted on the first day of June)

K = 0.053

Q_i = 21500 Kg = 215 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{215}{80}\right)^4 = 2.764$$

$$CESAL = 3 \times 2.764 \times 0.5 \times 0.78 \times 365 = 1.181 \times 10^3$$

Taking the 6A configuration in June for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 114 (Number of Mombasa bound 6A vehicles counted on the first day of June)

K = 0.053

Q_i = 26200 Kg = 262 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{262}{80}\right)^4 = 6.097$$

$$CESAL = 114 \times 6.097 \times 0.5 \times 0.78 \times 365 = 98.94\, x\, 10^3$$

Table A3- 5: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	113	170.3	0.5	0.78	365	2739475
3A	86	9.893	0.5	0.78	365	121115.5
4A	3	2.764	0.5	0.78	365	1180.724
6A	114	6.097	0.5	0.78	365	98942.62
Total						2960714

Table A3- 6: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	113	3.898	0.5	0.78	365	62701.47
3A	86	3.679	0.5	0.78	365	45038.69
4A	3	5.934	0.5	0.78	365	2534.115
6A	114	6.003	0.5	0.78	365	97416.08
Total						207690.4

$$RSL = \frac{\mathbf{207690.4}}{\mathbf{2960714}} \times \mathbf{15} = \mathbf{1.052}$$

Taking the 2A configuration in the month of July for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 197 (Number of Mombasa bound 2A vehicles counted on the first day of July)

K = 1

Q_i = 27600 Kg = 276 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{276}{80}\right)^4 = 141.7$$

$$CESAL = 197 \times 141.7 \times 0.5 \times 0.78 \times 365 = 3972.8\, x\, 10^3$$

Taking the 3A configuration in the month of July for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 174 (Number of Mombasa bound 3A counted on the first day of July)

K = 0.086

Q_i = 25800 Kg = 258 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{258}{80}\right)^4 = 9.303$$

$$CESAL = 174 \times 9.303 \times 0.5 \times 0.78 \times 365 = 230.4\, x \;\; 10^3$$

Taking the 4A configuration in July for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 5 (Number of Mombasa bound 4A vehicles counted on the first day of July)

K = 0.053

Q_i = 25200 Kg = 252 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{252}{80}\right)^4 = 5.218$$

$$CESAL = 5 \times 5.218 \times 0.5 \times 0.78 \times 365 = 3.714 \times 10^3$$

Taking the 6A configuration in July for Mombasa bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 178 (Number of Mombasa bound 6A vehicles counted on the first day of July)

K = 0.053

Q_i = 27900 Kg = 279 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{279}{80}\right)^4 = 7.84$$

$$CESAL = 178 \times 7.84 \times 0.5 \times 0.78 \times 365 = 198.7\, x\, 10^3$$

Table A3- 7: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	197	141.7	0.5	0.78	365	3972831
3A	174	9.303	0.5	0.78	365	230422.1
4A	5	5.218	0.5	0.78	365	3714.031
6A	178	7.84	0.5	0.78	365	198659.9
Total						4405627

Table A3- 8: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	197	3.898	0.5	0.78	365	109311.4
3A	174	3.679	0.5	0.78	365	91124.78
4A	5	5.934	0.5	0.78	365	4223.525
6A	178	6.003	0.5	0.78	365	152105.8
Total						356765.5

$$RSL = \frac{\mathbf{356765.5}}{\mathbf{4405627}} \times \mathbf{15} = \mathbf{1.215}$$

ii. Nairobi Bound Traffic

Taking the 2A configuration in the month of April for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 430 (Number of Nairobi bound 2A vehicles counted on the first day of April)

K = 1

Q_i = 27600 Kg = 276 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{276}{80}\right)^4 = 141.7$$

$$CESAL = 430 \times 141.7 \times 0.5 \times 0.78 \times 365 = 8671.7\, x\, 10^3$$

Taking the 3A configuration in the month of April for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 145 (Number of Nairobi bound 3A counted on the first day of April)

K = 0.086

Q_i = 26600 Kg = 266 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{266}{80}\right)^4 = 10.51$$

$$CESAL = 145 \times 10.51 \times 0.5 \times 0.78 \times 365 = 217\ x\ \ 10^3$$

Taking the 4A configuration in April for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 12 (Number of Nairobi bound 4A vehicles counted on the first day of April)

K = 0.053

Q_i = 25200 Kg = 252 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{252}{80}\right)^4 = 5.218$$

$$CESAL = 12 \times 5.218 \times 0.5 \times 0.78 \times 365 = 8.913 \times 10^3$$

Taking the 6A configuration in April for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 619 (Number of Nairobi bound 6A vehicles counted on the first day of April)

K = 0.053

Q_i = 27600 Kg = 276 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{276}{80}\right)^4 = 7.508$$

$$CESAL = 619 \times 7.508 \times 0.5 \times 0.78 \times 365 = 661.6\ x\ 10^3$$

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented below:

Table A3- 9: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	430	141.7	0.5	0.78	365	8671661
3A	145	10.51	0.5	0.78	365	216965.4
4A	12	5.218	0.5	0.78	365	8913.675
6A	619	7.508	0.5	0.78	365	661607.4
Total						9559148

Table A3- 10: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	430	3.898	0.5	0.78	365	238598.5
3A	145	3.679	0.5	0.78	365	75937.32
4A	12	5.934	0.5	0.78	365	10136.46
6A	619	6.003	0.5	0.78	365	528952.2
Total						853624.6

$$RSL = \frac{\mathbf{853624.6}}{\mathbf{9559148}} \times \mathbf{15} = \mathbf{1.339}$$

Taking the 2A configuration in the month of May for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 306 (Number of Nairobi bound 2A vehicles ` counted on the first day of May)

K = 1

Q_i = 28100 Kg = 281 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{281}{80}\right)^4 = 152.2$$

$$CESAL = 306 \times 152.2 \times 0.5 \times 0.78 \times 365 = 6630.5\, x\, 10^3$$

Taking the 3A configuration in the month of May for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 37 (Number of Nairobi bound 3A counted on the first day of May)

K = 9.018

Q_i = 25600 Kg = 256 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{256}{80}\right)^4 = 9.018$$

$$CESAL = 37 \times 9.018 \times 0.5 \times 0.78 \times 365 = 475\, x\ \ 10^3$$

Taking the 4A configuration in May for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 2 (Number of Nairobi bound 4A vehicles counted on the first day of May)

K = 0.053

Q_i = 26100 Kg = 261 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{261}{80}\right)^4 = 6.005$$

$$CESAL = 2 \times 6.005 \times 0.5 \times 0.78 \times 365 = 1.709 \times 10^3$$

Taking the 6A configuration in May for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 515 (Number of Nairobi bound 6A vehicles counted on the first day of May)

K = 0.053

Q_i = 26300 Kg = 263 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{263}{80}\right)^4 = 6.191$$

$$CESAL = 515 \times 6.191 \times 0.5 \times 0.78 \times 365 = 453.8\, x\ 10^3$$

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented below

Table A3- 11: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	306	152.2	0.5	0.78	365	6630469
3A	37	9.018	0.5	0.78	365	47496.06
4A	2	6.005	0.5	0.78	365	1709.485
6A	515	6.191	0.5	0.78	365	453840.9
Total						7133515

Table A3- 12: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	306	3.898	0.5	0.78	365	169793.4
3A	37	3.679	0.5	0.78	365	19377.11
4A	2	5.934	0.5	0.78	365	1689.41
6A	515	6.003	0.5	0.78	365	440081.4
Total						630941.3

$$RSL = \frac{\mathbf{630941.3}}{\mathbf{7133515}} \times \mathbf{15 = 1.327}$$

Taking the 2A configuration in the month of June for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 278 (Number of Nairobi bound 2A vehicles counted on the first day of June)

K = 1

Q_i = 26100 Kg = 261 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{261}{80}\right)^4 = 113.3$$

$$CESAL = 278 \times 113.3 \times 0.5 \times 0.78 \times 365 = 4483.4\,x\,10^3$$

Taking the 3A configuration in the month of June for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 87 (Number of Nairobi bound 3A counted on the first day of June)

K = 0.086

Q_i = 26300 Kg = 263 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{263}{80}\right)^4 = 10.04$$

$$CESAL = 87 \times 10.04 \times 0.5 \times 0.78 \times 365 = 124.4\, x\ \ 10^3$$

Taking the 4A configuration in June for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 2 (Number of Nairobi bound 4A vehicles counted on the first day of June)

K = 0.053

Q_i = 24000 Kg = 240 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{240}{80}\right)^4 = 4.293$$

$$CESAL = 2 \times 4.293 \times 0.5 \times 0.78 \times 365 = 1.222 \times 10^3$$

Taking the 6A configuration in June for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 627 (Number of Nairobi bound 6A vehicles counted on the first day of June)

K = 0.053

Q_i = 27700 Kg = 277 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{277}{80}\right)^4 = 7.618$$

$$CESAL = 627 \times 7.618 \times 0.5 \times 0.78 \times 365 = 679.9\, x\, 10^3$$

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented below

Table A3- 13: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	278	113.3	0.5	0.78	365	4483368
3A	87	10.04	0.5	0.78	365	124405.1
4A	2	4.293	0.5	0.78	365	1222.217
6A	627	7.618	0.5	0.78	365	679923.4
Total						5288918

Table A3- 14: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	278	3.898	0.5	0.78	365	154256.7
3A	87	3.679	0.5	0.78	365	45562.39
4A	2	5.934	0.5	0.78	365	1689.41
6A	627	6.003	0.5	0.78	365	535788.5
Total						737297

$$RSL = \frac{\mathbf{737297}}{\mathbf{5288918}} \times \mathbf{15} = \mathbf{2.091}$$

Taking the 2A configuration in the month of July for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 414 (Number of Nairobi bound 2A vehicles counted on the first day of July)

K = 1

Q_i = 26200 Kg = 262 kN

Q_S = 80 kN

$$VDF = 1\left(\frac{262}{80}\right)^4 = 115$$

$$CESAL = 414 \times 115 \times 0.5 \times 0.78 \times 365 = 6779.6\, x\, 10^3$$

Taking the 3A configuration in the month of July for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 108 (Number of Nairobi bound 3A vehicles counted on the first day of July)

K = 9.743

Q_i = 26100 Kg = 261 kN

Q_S = 80 kN

$$VDF = 0.086\left(\frac{261}{80}\right)^4 = 9.743$$

$$CESAL = 108 \times 9.743 \times 0.5 \times 0.78 \times 365 = 149.8\, x \;\; 10^3$$

Taking the 4A configuration in July for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 2 (Number of Nairobi bound 4A vehicles counted on the first day of July)

K = 0.053

Q_i = 22800 Kg = 228 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{228}{80}\right)^4 = 3.497$$

$$CESAL = 2 \times 3.497 \times 0.5 \times 0.78 \times 365 = 0.996 \times 10^3$$

Taking the 6A configuration in July for Nairobi bound traffic the CESAL will be:

D_D = 0.5 (For trucks)

D_L = 0.78 (2 lanes per direction, Trucks)

N_j = 416 (Number of Nairobi bound 6A vehicles counted on the first day of July)

K = 0.053

Q_i = 26800 Kg = 268 kN

Q_S = 80 kN

$$VDF = 0.053\left(\frac{268}{80}\right)^4 = 6.675$$

$$CESAL = 416 \times 6.675 \times 0.5 \times 0.78 \times 365 = 395.3\, x\, 10^3$$

Summaries of the CESAL for the different vehicle configurations for both overloaded and standard traffic are presented

Table A3- 15: Estimated traffic in the design life of pavement (overload)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	414	115	0.5	0.78	365	6779584
3A	108	9.743	0.5	0.78	365	149789.6
4A	2	3.497	0.5	0.78	365	995.5035
6A	416	6.675	0.5	0.78	365	395281
Total						7325650

Table A3- 16: Estimated traffic in the design life of pavement (standard)

Vehicle Type	N_j	VDF_j	D_D	D_L	Number of days	Design Traffic (CESAL)
2A	414	3.898	0.5	0.78	365	229720.4
3A	108	3.679	0.5	0.78	365	56560.21
4A	2	5.934	0.5	0.78	365	1689.41
6A	416	6.003	0.5	0.78	365	355483.3
Total						643453.3

$$RSL = \frac{\mathbf{643453.3}}{\mathbf{7325650}} \times \mathbf{15} = \mathbf{1.318}$$

Appendix 4: Sample of Questionnaire used

UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL & CONSTRUCTION ENGINEERING

INSTRUCTIONS:

- This questionnaire shall be used for research purposes only
- Any information given will be kept confidential

Date : ....

Name of interviewee : ....

Location : ....

Questionnaire Number: ....

Vehicle No Plate : ....

A. Personal Data (Optional) (Tick where applicable)

Age (Years)		Gender		Role		Employment		Cargo transport experience (Years)
18 – 25		Male		Driver		Owner		
26 – 35								
36 – 45								
46 – 55		Female		Turn boy		Employed		
56 - 60								
61 and above								

B. General Perspectives

a) What is the name of the company/organization of employment?

....

b) Does your employer have any guidelines on loading and how to regulate axle loads before transport begins?

....

c) Which type of axle is your vehicle?

....

d) Which type of goods do you transport?

---

e) What is the average gross weight of goods transported per day?

---

f) Type of distance travel?
   I. Long distance ☐
   II. Short distance ☐

g) Load destination: ---

h) Are you aware of the legal gross weight (GVW) loading limits?
   I. Yes ☐
   II. No ☐

i) If yes, do you make a conscious effort to adhere to these limits?

---

j) Do you, or have you ever overloaded your vehicle?
   I. Yes ☐
   II. No ☐

k) If yes, how many times have you been caught overloading?

---

l) Are you aware of the penalties or charges imposed for overloading?
   I. Yes ☐
   II. No ☐

m) If No, why? And what can be done to make drivers more aware?

---

n) Who pays for the charges incurred after overloading?

Additional comments:

*****Thank you so much for completing the survey! We really appreciate your input!