UNIVERSITY OF NAIROBI

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

TRUCK PARKING REQUIREMENTS: THE CASE OF ATHI RIVER WEIGHBRIDGE LOCATED ALONG MOMBASA NAIROBI HIGHWAY

A thesis submitted in partial fulfillment of the requirements for the award of Degree of Master of Science in Civil Engineering, in the Department of Civil Engineering of the University of Nairobi

By

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November, 2021

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DEDICATION

I dedicate this thesis to the Trucking Crew and Operators on the Northern Transport Corridor, who deserve improved roadside amenities and hubs, for supporting logistics and making the corridor attractive and competitive.

ABSTRACT

Truck parking facilities are an important element in Kenya's transportation system, the shortage of which can lead to high economic costs and national safety concerns.

This study seeks to determine operational, design and management challenges at the *Athi River* Weighbridge Station, in relation to the supply and demand dynamics of truck parking. It reviewed factors that influenced the location of the weigh station and identified the design considerations that informed the establishment of the weighbridge. This included an estimation of parking demand due to weighbridge operations, by use of a modelling approach that considered daily volume of trucks traveling across the segment, and the duration of stops anticipated both in the short-term and long-term. Field observations were also used to develop and calibrate the model.

The results revealed that the *Athi River* Weighbridge operations contributed to only 19% of the aggregate parking demand, with 65.8% of this being less than thirty minutes' duration, and the rest ranging between thirty minutes and a one-hour duration. Further, most of the trucks that were parked for less than thirty minutes or between thirty minutes and an hour, was primarily due to queuing into the weighbridge.

The study finds that the Nairobi Expressway from Mlolongo – JKIA – James Gichuru, the first "Real Toll Road" in Kenya (where the CAPEX is solely funded by the private sector and the cash flow generated from tolling and other operation revenues), could have taken advantage of developing the parking facility to enhance the revenue over the concession period and reduce the payback period.

This study recommends that analytical tools, such as the multi linear regression analysis be used to model current and future demand for truck parking facilities in all weigh bridge locations.

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ACRONYMS

AADT	Annual Average Daily Traffic
ALCS	Axle Load Control Stations
ANPR	Automatic Number Plate Recognition
AWIMS	Axle Weight Information Management System
Capex	Capital Expenditure
CCTV	Close Circuit Television
CESAs	Cumulative Equivalent Standard Axles
COMESA	Common Market for East and Southern Africa
CPA	Contract Price Adjustment
CSA	Cumulative Standard Axle
DB	Database
DL	Driving License
EAC	East African Community
EF	Equivalence Factor
EIRR	Economic Internal Rate of Return
EPC	Engineering Procurement and Construction
ESA	Equivalent Standard Axles
EU	European Union
FIRR	Financial Rate of Return
FTCC	Full Traffic Control Centre
GCM	Gross Combination Mass

GOK	Government of Kenya
GVW	Gross Vehicle Weight
HOS	Hours of Service
HSWI	High Speed Weigh in Motion
ID	Identification
KeNHA	Kenya National Highway Authority
KRB	Kenya Roads Board
KURA	Kenya Urban Roads Authority
LAPSET	Lamu-Southern Sudan-Ethiopia Transport
LSWIM	Low Speed Weigh-In-Motion (maximum 8km/h)
M&O	Maintenance and Operation
MCBRTA	Multilateral Cross-Border Road Transport Agreement
MLCU	Mobile Load Control Unit
MORPW	Ministry of Roads and Public Works
MOTI	Ministry of Transport and Infrastructure
NC	Northern Corridor
NCTTCA	Northern Corridor Transit and Transport Coordination Authority
NPV	Net Present Value
NRA	Namibia Roads Agency
OCR	Optical Character Recognition
OL	Overload
OLC	Overload Control

OLCI	Overload Control Index
Opex	Operating Expenditure
PC	Personal Computer
PDA	Personal Digital Assistant (handheld computer)
REC	Regional Economic Community
RMI	Road Maintenance Initiative
RTQS	Road Transport Quality System
RTRN	Regional Trunk Route Network
RWBLP	Regional Weighbridge Location Plan
SADC	Southern African Development Community
SANRAL	South African National Roads Agency Ltd
SPV	Special Purpose Vehicle
SS	Static Scale
SSATP	Sub-Saharan Africa Transport Policy
TANROADS	Tanzania National Roads Agency
TCBRTC	Tripartite Cross-Border Road Transport Commission
TCC	Traffic Control Centre
TMC	Traffic Management Centre
TRN	Trunk Route Network
Tripartite	COMESA, EAC & SADC
TRIPS	Transport Registers and Information Platform and System
UNES	University of Nairobi Enterprise Service

VPN	Virtual Private Network
WB	Weigh Bridge
WIM	Weigh-In-Motion
WS	Weigh Station

CHAPTER ONE: INTRODUCTION

1.1 Background

The road freight transport industry is an important part of Kenya's economic development. According to the Northern Corridor Transit and Transport Coordination Authority (NCTTCA, 2016), approximately 95 percentage of non-bulk freight along East Africa's Northern Corridor is transported by road, which provides advantages in terms of superior reliability, competitive prices, convenience, and speed. Based on a weighbridge location study by the European Union (EU), the Northern Corridor is described as part of the Trunk Route Network (TNR) 8 and is a multi-modal corridor, consisting of road, rail, pipeline, and inland waterways transport. It originates at the gate port of *Mombasa* (Kenya), and terminates at *Bujumbura* (Burundi) via *Mbarara* (Uganda) and *Kigali* (Rwanda), and at *Kisangani* via *Mbarara* and *Beni* (See Figure 1.1)

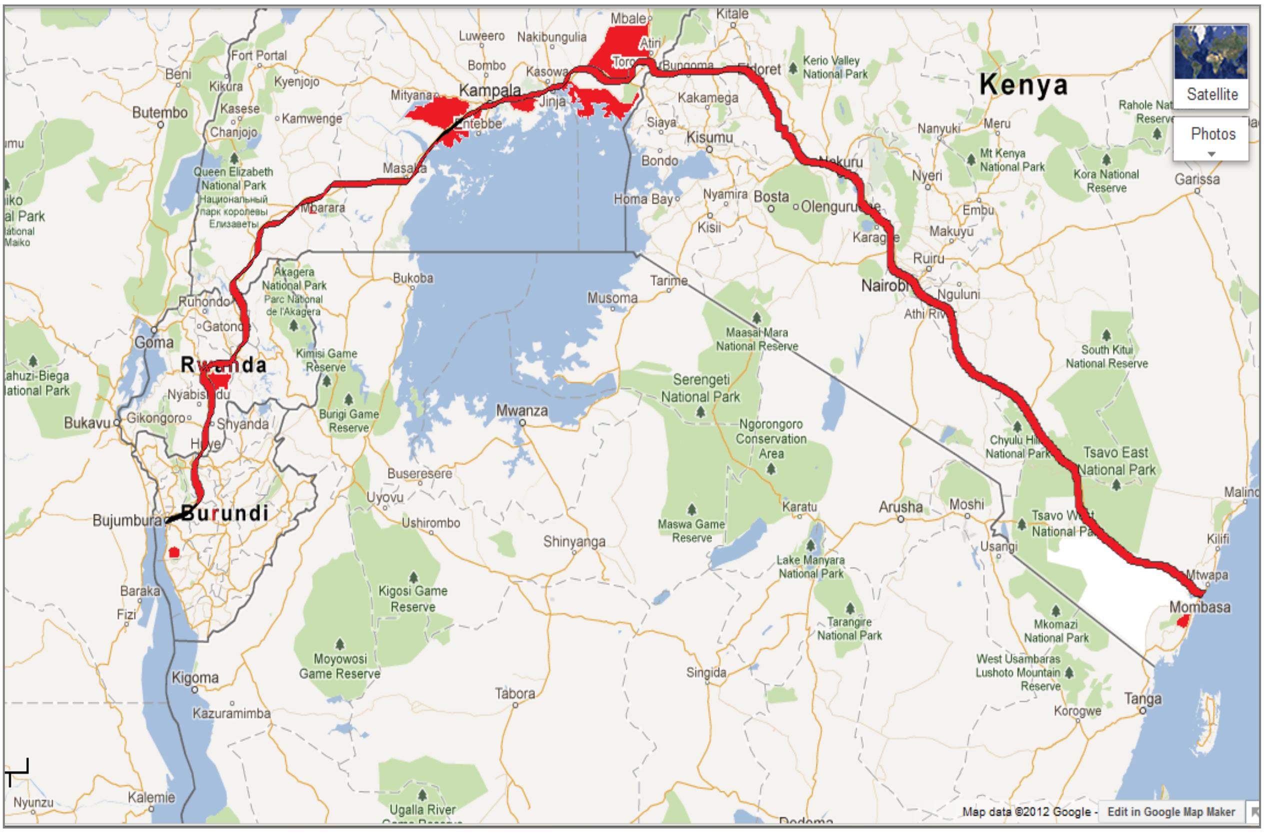

Figure 1.1 The Northern Corridor Transportation Network

Source: Google, 2012

With the amount of freight traffic in the Northern Corridor region increasing by 20 percent annually (NCTTCA, 2016), there has been a subsequent increased demand for truck parking facilities at the weighbridge network (See Figure 1.2). Markedly, scarce parking compels truck drivers to either park in unsafe locations or along the highway shoulders, which further impedes traffic that would normally use these facilities. This is more pronounced at locations within the immediate vicinity of the weighbridges that have mushroomed to provide commercial and social services including rest, repair, maintenance, and truck stopping requirements to the crew.

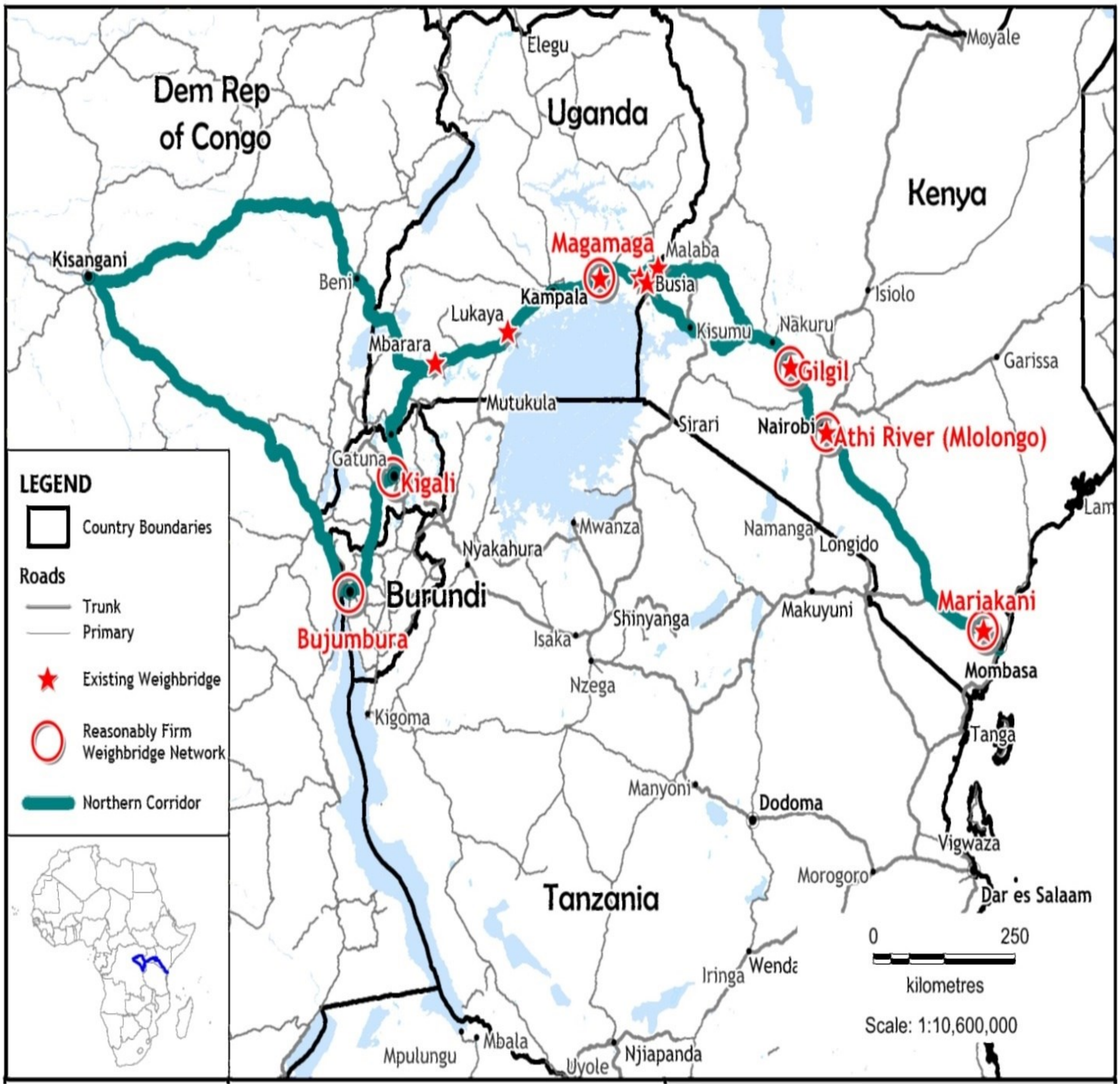

Figure 1.2 Weighbridge Network for the Northern Corridor

Source: EU Report on African Weighbridges, 2014

Evidence suggests that the unplanned situation of truck parking facilities along the Northern Transport Corridor is a function of inadequate parking capacity that is compounded by overall congestion at the weighbridges. Arguably, public weigh stations have, in some cases, been identified for overflow parking (Beltemacchi & Manning, 2008).

Currently, the Kenya National Highways Authority operates four (4) Weighbridges (WB) along the multi-modal corridor namely: *Mariakani* situated at 27 kilometres; *Athi River* situated at 500 kilometres; *Gilgil* situated at 600 kilometres from the port of *Mombasa;* and *Webuye* situated at 700 kilometres from the port of *Mombasa* and 300 kilometres to the border with Uganda at *Malaba*. The locations of these weighbridges follow a logical pattern and provide good control of traffic on the Northern Corridor, to include heavy vehicle traffic from the feeder network within Kenya. This study highlights the purposes of the weighbridges as follows:

- *Mariakani* (See Plate 1.1) controls traffic near *Mombasa* City that originates from the port into the hinterland, and into Tanzania through the *Taveta* border.
- *Athi River* (See Plate 1.2 and 1.3) controls traffic along the central portion of the Northern Corridor, as well as traffic to the Eastern districts of *Kitui* and *Kibwezi* and to Tanzania via *Namanga*.
- *Gilgil* (See Plate 1.4) provides control for the Northern Corridor traffic between Nairobi and the Western districts of Kenya.
- *Webuye* controls the heavy vehicle traffic along the Northern Corridor that includes traffic to and from *Kisumu, Kitale* and the Northwest of Kenya. It also provides additional control for the Western end of the Northern Corridor.

Typically, most jurisdictions in developed economies have parking lot ordinances and criteria for providing designated parking areas, with lots being either on-street or off-street. In most cases, on-street truck parking lots and facilities are privately owned but publicly required (Manville et al. 2005). It is important for consideration to be given to the definition of the type of traffic the lot is expected to serve, the location characteristics related to land use space dimensions, lot geometry, in situ subgrade, proximity to services and the overall local development plans, regulations and ordinances.

Plate 1.1 Mariakani Weighbridge
Source: Author 2016

Plate 1.2 Old Weighbridge at Athi River
Source: Author, 2016

Plate 1.3 Weighbridge at Athi River
Source: Author, 2016

Plate 1.4: Weighbridge at Gilgil
Source: Author, 2016

This study observes that at many of the weigh stations along the Northern Corridor, only holding areas for non-compliant vehicles were provided within the layout plans. Accordingly, planning for truck parking facilities was not integrated in the highway development and improvement plans, until recently (Northern Corridor Roadside Stations Guidelines, 2016). Indeed, it appears that the extent of the shortfall will require a dramatic increase in the supply of safe and convenient parking facilities for commercial trucks, along with the improved management of existing resources.

In recent years, economic developments, such as the implementation of just-in-time delivery for inventory and regulation changes, including restrictions on the maximum hours of driving for truck drivers, have altered the operational nature of the business, adding to the increased demand for parking (Beltemacchi and Manning, 2008). Moreover, evidence suggests that delays to the road-based portion of goods' movements along the Northern Corridor due to long transit times, high transportation costs and parking limitations can have cascading effects on the rail and maritime portions of the supply chain.

The following section describes these challenges as they are manifested at *Athi River* Weighbridge-a Full Traffic Control Centre (FTCC) facility, which experiences high truck parking volumes throughout the year. Truck-parking along the shoulders of the highway and on the road reserves due to lack of a parking facility, which poses road safety challenges to other road users, is a source of serious environmental pollution, as well as visual intrusion.

1.2 Study Area

Athi River, also known as *Mavoko*, is a town situated on the Eastern outskirts of Nairobi along the Nairobi-Mombasa highway (See Plate 1.5). It is the main town within *Mavoko* Municipal Council, and hosts the Municipal Council Head Office, which is part of *Machakos* County. Named after the *Athi-Galana River,* the town has since grown from a railway sub-station built in 1920, to a predominantly industrial center. Cement, steel industries and the Export Processing Zone (EPZ), which concentrates on textiles, have become synonymous with *Athi River* Town.

Plate 1.5 *Mlolongo* Weighbridge Area

Source: Google Maps, 2016

The Weighbridge Station was upgraded to a Full Traffic Control Center (FTCC) weighing stations on both sides of the highway (KeNHA , 2010). A FTCC includes the following range of facilities for efficiently and effectively undertaking an overload control process at minimum disruption to relatively large volumes of heavy vehicle traffic:

1. A low-speed weigh-in-motion (LSWIM) screening device for confirmation of vehicles suspected to be overloaded as indicated by the HSWIM and a static platform scale for accurately weighing axle loads and load distribution for prosecution purposes.
2. A high-speed weigh-in-motion (HSWIM) screening device in the auxiliary lane where vehicles weighing above 3.5 tons are diverted into from the main highway (See Plate 1.6).

Plate 1. 6 The HSWIM Screening Device at the *Athi River* Weighbridge

Source: Author, 2019

According to the Kenya Population and Housing Census, *Machakos* County has a population of 1,421,932, with an average population density at 239 per square kilometer. (Kenya Bureau of Statistics 2019). *Mlolongo*, is Swahili for 'long line' and the name is because of the long queues experienced by truck drivers as they await mandatory service at the weighbridge established in 1979 by the Ministry of Roads, the weighbridge. All heavy trucks along the Northern Corridor from Mombasa Port headed into Nairobi and further into Western Kenya or the neighboring East African countries, must pass through the *Athi River/Mlolongo* Weigh Station.

It links the Republic of Southern Sudan, Northern United Republic of Tanzania and the Federal Democratic Republic of Ethiopia in the North and connects with the *Lamu* Port-Southern Sudan-Ethiopia Transport (LAPSSET) Corridor Project and has great influence on the traffic flow patterns within Nairobi and the socio-economic dynamics of *Athi River* Town are closely associated with the trucking industry.

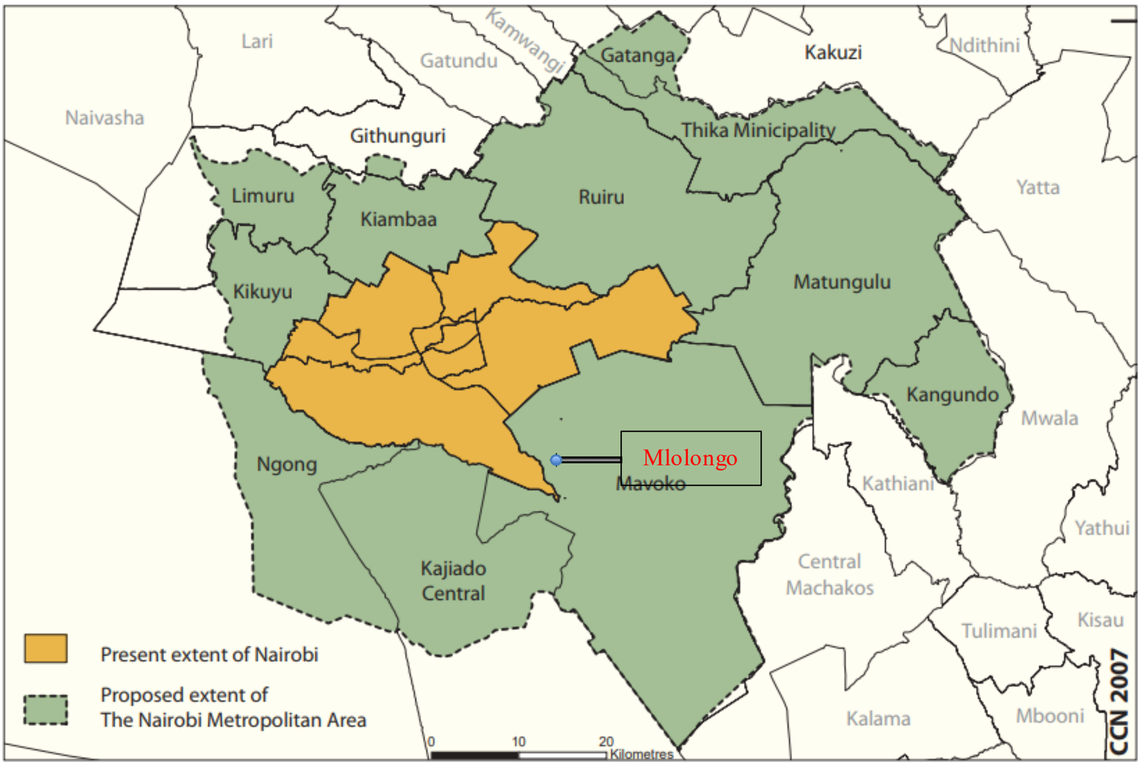

Figure 1.3 ***Mlolongo*** **Town in relation to Nairobi Metropolitan Area**
Source: UNEP, 2003

Figure 1. 4 Mlolongo Town Aerial View
Source: Google Earth, 2018

1.2.1 Housing and Social Services

Mlolongo Town has both permanent and semi-permanent housing for its residents, which grew in unplanned developments. Most of the residential spaces within the town are in mixed-use with commercial areas that serve the residents of the town and their guests. Further, the town is home to a significant number of lodgings and hotels that provide accommodation services to truck drivers and passengers.

There are educational institutions in *Mlolongo* Town such as *Mlolongo* Primary School and several training institutions for the residents. The town has three health clinics, which serve both the residents and truck drivers on transit.

1.2.2. Industries and Commercial Activities

Machakos County has 114 manufacturing industries, most of which are in *Mavoko* Constituency. *Athi River* has many mineral deposits such as sand, limestone, and granite, which are valuable to the construction industry, and attract many industries that require them as input materials. *Mavoko* hosts many cement companies such as Bamburi Cement (See Plate 1.7), East African Portland Cement, Simba Cement and Savanna Cement that, serve the entire country, and the Common Market for Eastern and Southern Africa countries. Other industries in the constituency include Kenya Meat Commission (K.M.C), Mabati Rolling Mills, Athi River Steel Plant and Agrichem Ltd respectively (CIPD,2015).

Plate 1.7 ***Bamburi*** **Cement Plant in** ***Athi River***

Source: CIPD, 2015

Mlolongo Town counts as one of *Machakos* County's major market and urban centers. There are many commercial activities in the town, creating an almost 24-hour economy. The town is home to two major supermarkets, banks and micro financing institutions and other small businesses.

1.2.3. Employment and Income Distribution

There are few wage earners in *Mlolongo*, with only 11% of the employable population being in formal employment. Most of the employed are casual laborers working in the industries. The larger working populace in *Mlolongo* engages in small businesses within the urban center, most of which remain unregulated. However, the unemployment rate stands at a high of 52% with a very large number of unproductive youth (CIPD, 2015).

1.2.4. Environment and Climate Change

Machakos County is not new to environmental degradation given that it is the largest producer of sand for construction within the country. The sand harvesting business has proven to be detrimental to the environment because it leads to the drying up of rivers and degradation of riverbeds. This has further created a water scarcity issue within the area and affected the water quality for the residents of *Mlolongo* Town. The County Government of *Machakos* intends to regulate sand harvesting, to maximize the revenue opportunity, whilst reducing the impact of harvesting on the environment.

Moreover, numerous industries in the area have contributed towards increased air pollution in Mlolongo because of dust and emissions, thereby posing health hazards to the residents. The use firewood and charcoal, which are the main sources of fuel, further exacerbates deforestation.

1.3 Problem Statement

An efficient and effective axle load enforcement strategy is a practical approach towards addressing vehicle overloading and the consequences on the road condition. This is currently being undertaken through the operation of weighbridges along the transportation corridors in the East African Community region, with freight traffic stopping at these locations to undergo statutory monitoring. Essential for the weighbridge installation, is a High-Speed Weigh in Motion system, which screens compliant truck traffic with non-compliant components and the parking space used to detain non-compliant trucks.

Up to 2013, the infrastructure at *Athi River* Weighbridge consisted of a fixed single axle weighing scale with electronic screen and printout capability; two lanes with single axle scales; and offices for the weighbridge management staff (KeNHA, 2010). The old *Athi River* Weighbridge which was phased out in 2016 was on one side of the road (Mombasa bound side) which constrained trucks heading to Nairobi by forcing them to turn into the weighbridge-creating conflict with Mombasa bound vehicles. This situation was further exacerbated whenever a truck broke down while turning into the weighbridge (See Figure 1.6 below). In this regard, the weighbridge was upgraded to a Full Traffic Control Centre (FTTC). The detailed designs, however, did not account for the nationwide demand for effective truck parking.

Figure 1.5 Previous Mlolongo Weighbridge Layout
Source: Openstreetmap.org, 2018

Notably, the old weigh station only comprised of the low-speed static weigh in motion scale (LSWIM), which meant that each truck passing along the corridor, empty or not, would have to queue to be screened and weighed manually. According to Njuguna (2015), 53% of the trucks would spend 1-3 hours parked at *Mlolongo* awaiting service or taking a rest because of the long queues experienced at the weighbridge.

Additional research could clarify the reasons for the imbalance between truck parking supply and demand at Athi River Weighbridge. Amongst the factors that need to be considered include: national studies documenting shortages of truck parking facilities; a comprehensive analysis of the truck parking demand for transport corridors; an assessment of truck parking needs and preferences through stakeholder consultations; the provision of parking as a revenue generator and other requirements like non-motorized transport (NMT) facilities; offset details, landscaping, and future improvements based on land use changes.

According to a report on the Northern Corridor, the proportion of truck traffic to the Annual Average Daily Traffic (AADT) between *Mombasa* and *Nairobi* is approximately 14 percent and continues to grow at an annual rate of 5 percent (Nathan Associates , 2010). Notwithstanding, this truck traffic significantly contributes to pavement damage, poor road safety and exacerbation of congestion within the urban environment (See Plate 1.8).

Plate 1.8 Damaged gravel surface at the weighbridge location

Source: Author, 2018

Whereas the *Athi River* Weighbridge operates for 24 hours, due to the truck parking shortages and other facilities shortages along the transport corridor, truck drivers create unsafe conditions by driving without short breaks, or parking illegally on shoulders and ramps (See Plate 1.9). The safety of these heavy commercial vehicle operations is further compromised, particularly during the wet season, by several mud holes often filled with surface water at the weighbridge location.

Plate 1.9 Illegal truck parking along the highway in *Mlolongo*

Source: Author, 2019

Markedly, the parked truck vehicles tend to conflict with vehicles exiting the weighbridge, contributing to unfavourable operating space, littering and a polluted environment. The situation is further compounded by congestion and traffic delays due to long queues along the carriageway on the left lane, which impedes traffic flow on the segment (See Plate 1.10). Also restricting overall circulation are the narrow widths of the entry and exit to the static weighing scales.

Plate 1.10 Trucks queuing at the weighbridge facility

Source: Author, 2019

1.4 Research Questions

The following questions will form the basis of this research to achieve its main objectives:

1. Is parking along the *Athi River* Weighbridge Station adequate to meet truck demand?
2. Do the *Athi River* Weighbridge Station operations affect truck parking requirements at Mlolongo?
3. Should considerations be made to provide truck parking at *Mlolongo/Athi River* Weighbridge Station?
4. Can a model be adopted for future determination of truck parking demand at the *Mlolongo/ Athi River* Weighbridge Station?

1.5 Objectives of the Study

The main objective of this study is to identify the truck parking requirements in Mlolongo Town as a relates to the *Athi River* Weighbridge Station. As such, the specific objectives are:

1. To review whether parking along the *Athi River* Weighbridge Station is adequate to meet truck demand.
2. To establish whether the operations of the *Athi River* weighbridge station affect truck parking requirements at *Mlolongo*.
3. To determine considerations necessary to providing adequate truck parking at *Mlolongo/ Athi River* Weighbridge Station.
4. To adopt a suitable model for future determination of truck parking demand at the *Mlolongo/ Athi River* Weighbridge Station.

1.6 Scope and Limitations of the Study

This study investigated the truck parking facility requirements at the *Athi River* Weighbridge Station. It focused on parking demand with respect to parking volume; parking accumulation; parking duration and space, emanating from the challenges of the built environment along the

Northern Corridor. It is however noted that the Nairobi Expressway will enhance the efficiency of traffic flow and reduce delays experienced.

CHAPTER TWO: LITERATURE REVIEW

2.1. Overview

This chapter discusses previous studies, which have investigated the demand for and supply of truck parking facilities. It identifies specific issues associated with the shortage of parking spaces for trucks at rest areas and determines the remedial measures taken to address them. More specifically, this review highlights factors that influence decision making when determining parking lot requirements. Previous studies in Africa and Kenya have focused on existing amenities and facilities while investigating truck parking demand along regional networks. Nevertheless, a paucity exists in studies which identify the benefits associated with providing truck parking for commercial vehicles. In most cases, the benefits of providing parking result from addressing existing issues associated with limited parking availability.

2.2 Studies on Truck Parking Facilities at Weigh stations along the Northern Corridor

In recent years, numerous studies focused on parking demand estimations for a single parking facility and the subsequent adoption of truck parking demand models have been conducted along the Northern Corridor. However, there is a dearth of information on how to estimate truck parking demand for a given highway segment such as the *Athi River* Weighbridge Station.

2.2.1 Kenya

In Kenya, truck parking facilities and services are mainly situated at the seven fixed weighbridges between *Mombasa* and *Malaba* along the Northern Corridor. Three of the seven weighbridges have been licensed to private sector operators. Markedly, *Mariakani* and *Athi River* are the busiest along the corridor, experiencing delays of 3-4 hours compared to 1-2 hours at the other stations (Njuguna, 2015). The study noted that of the drivers sampled, 65% were on long- haul trips with many travelling to Eldoret, Kisumu, Busia and Uganda. Further, interviews with truck drivers revealed that 43% were parked at the station as they awaited their weighing turn and another 43% were parked for overnight rest.

Markedly, there were no designated parking areas for trucks at the weigh station, with only a holding yard provided for non-compliant vehicles. As such, most trucks were parked along the shoulders of the road, creating chaos, constricting the highway, and exposing the trucks to theft or accidents. Findings revealed that the local land use and planning guidance may not be consistent with good guidance for accommodating large volumes of heavy trucks at the *Athi River* Weighbridge. Similarly, local design specifications for roadway infrastructure and traffic control devices are ill equipped to accommodate heavy truck volumes experienced.

The following were the strengths and weaknesses of Kenya's *Athi River* Weighbridge case study:

- A comprehensive overview of the truck parking situation at the *Athi River* Weighbridge Station has been provided, which can be utilized towards the development of data collection tools.
- The qualitative data outlines why truck drivers park around the weighbridge station, which is an important consideration when adopting a truck parking model for assessment.
- Statistics reveal that most of the drivers parked around the *Athi River* Weighbridge are on long haul trips, which contributes towards the adoption of an appropriate model.
- This study, however, does not propose any methods or criteria for determining the parking demand or parking space required to alleviate the parking shortages experienced at *Athi River*.

Another study by Odula (2016) assessed the capacity and utilization of the *Gilgil* Weighbridge Station along the Northern Corridor. In this study, Heavy Goods Vehicle (HGV) traffic counts and parking surveys were conducted at the holding bay and external parking area. Axle overload data for three years (2012 − 2014) was used to calculate the design weighbridge traffic and capacity, which was projected over a period of 20 years. The queuing model was used to analyze the efficiency of the station in terms of various parameters such as flow rate, arrival rate, service rate and system utilization. Findings revealed that the *Gilgil* Weighbridge Station was characterized by long delays, averaging 9.12 minutes per truck, and heavy congestion at the entry and exit points. The study further highlighted that the weighing capacity of the station had already been exceeded and the system was over utilized, leading to delays and high economic costs.

Many of the truck drivers interviewed pointed out that the main challenge they faced at the weighbridge station were lengthy service times and prevalence of corruption that hampered the swift passage of the trucks. Key recommendations of this study included increasing the number of servers and reviewing the station layout to improve the flow and control of vehicles.

The following are the main strengths and weaknesses of the *Gilgil* Weighbridge Station case study:

- The service and waiting times at *Gilgil* Weigh Station were quantified, clearly illustrating why it was necessary to have some parking facilities provided and controlled, aside from the holding yard.
- The study was mainly concerned with the operations of the weigh station itself, its efficiency and the challenges faced in ensuring proper service. It, however, did not provide a situational analysis of the existing parking situation at *Gilgil* or the parking requirements of the station.

A report by TMEA (2014) compared existing and projected supply and demand of truck parking facilities along the Northern Corridor that is estimated to serve over 200 million people. Investigations involved stakeholder interviews with truck drivers, weighbridge officers and freight transport associations, traffic counts and other investigations. Findings revealed that weighbridges have affected the flow of traffic along the corridor primarily because of the delays experienced in waiting for service at the stations. This had a subsequent impact on freight travel time. Kenya’s regulatory authority, KeNHA, formulated a policy in 2012 prohibiting all other activities within 2km of the weighbridge station, meaning that services such as restaurants, retailers and recreational rest spots cannot be accessed near the weighbridge (TMEA, 2014).

According to Pinard (2010), Namibia has developed an effective criterion for siting weighbridges depending on amongst others, the number of heavy vehicle traffic; the presence of services to support the crew and the strategic network development plans that have the potential to attract and generate heavy vehicle traffic. Notably, locating public parking areas at a weighbridge would rationalize placement of the rest area, achieving economies of scale and concentrating investments and resources in one location while ensuring efficiency. Further, establishing a parking facility within the environs of a weighbridge can help ease congestion along the corridor, allowing trucks access to repair and maintenance facilities. This ensures that freight trucks meet required standards during the entire journey.

The study recommended that the configuration of a weighbridge maintains the basic layout traditionally prescribed in weigh station design. However, it did not provide guidance on how to integrate truck parking demand within a weigh station related to all independent variables that contribute to the parking demand like non-compliance, rest needs, maintenance, and access to other services.

Kenya has regulated driving hours for commercial vehicles to a maximum of 8hrs within a 24-hour period. However, TMEA (2014) using a European directive on driving time, provided for a maximum of 9 hours with 4.5 hours driving time in their estimations of truck parking demand. Considering an average driving speed of 30km/hr. and a peak hour factor of 15%, the report estimated that within the Mombasa-Nairobi Section, 588 parking spaces were required (See Table 2.1 below)

Table 2. 1 Estimated Parking Demand along the Northern Corridor

Section	*Distance (Km)*	*Time (Hrs.)*	*Trucks*	*Driving Time(Hrs.)*	*Number of stops in the section*	*Number of Trucks x stops*	*Parking spaces required*
Mombasa-Nairobi	445.7	14.86	1,187	4.5	3.30	3,919.33	588

Source: TMEA, 2014

2.3 Adequacy of Truck Parking Spaces against Demand

2.3.1. Canada

According to Montufar Associates (MA) (2009) the shortages in truck parking capacity experienced in Canada are due to increasing truck traffic flows and the general demand in trucking operations. This is further exacerbated by increasing truck sizes that decrease space availability along corridors, since trucks with multiple trailers occupy several parking spaces. Consequently, truck drivers resort to driving while fatigued or parking illegally on and off ramps or highway shoulders because of the increased regulations on truck driver hours. The study also estimated the supply and demand for truck parking, including spaces at public rest areas, pull-offs, and private truck stops, on Saskatchewan's National Highway System (NHS) using a corridor-based approach.

Data was collected from existing literature on truck parking, consultations with experts including representatives from the Transportation Research Board (TRB) and interviews with truck drivers and their respective associations. Stakeholder involvement is essential towards the determination of truck parking needs along a given corridor serving a variety of interests in both the public and private sector.

This macroscopic study reviews the overall demand on an entire transport system and helps establish the imbalance in the aggregate supply and demand of truck parking facilities. It represents the total sum of individual highway links, derived from individual facilities, that attract truck parking and is a strong basis for decision making at the regional level with regards to the sector investment planning and investment. Arguably, supply and demand assessment on a strategic level may not be adequately applied to determination of highway truck parking requirements.

2.3.2. United States of America

Progressively, the United States is undergoing a remarkable growth in commercial truck travel on the national roadway system. According to Rodier et al (2007), truck parking demand in California exceeds the capacity at all public rest areas and 88% of private stops on 34 freight corridors with the highest truck volumes. It was also estimated that the demand for private truck parking in California will increase by 100% in 2020. The ongoing parking shortage was attributed to many causes, including land zoning, land prices, lack of coordination between states, and disparate efforts for addressing parking shortages between states. Markedly, tight delivery schedules associated with just-in-time delivery result in demand for truck parking spaces near loading or unloading facilities.

Private parking facilities are preferred by drivers for long term or overnight stays as opposed to public facilities, primarily because of perceived increased security which is important to freight drivers and owners. Research posits that efforts to quantify truck parking are constricted by seasonal fluctuations in freight movement, severe weather events, and variations in demand, due to time-of-day and day-of-week.

Against this background, Garber et al. (2005) reiterates Section 4027 of the Transportation Equity Act (TEA) that requires all states to determine and address shortages of commercial vehicle parking. This was in response to a national survey of 2,000 drivers conducted by the Owner-Operator Independent Driver Association (OOIDA), which established that the poor design and scarcity of safe truck parking spaces, was causing drivers to violate hours-of-service (HOS) regulations defined by the Interstate Commission. These rules determine limits on the number of hours that truck drivers may drive and be on duty before being required to take a mandatory rest break. Nonetheless, such rules must be balanced against on-time delivery requirements including shorter lead times for truck drivers to plan their trips, thus making location of rest area facilities and parking availability more critical.

Due to the parking shortages and limits on stays in parking facilities, truck drivers tend to create unsafe situations by parking illegally along highway shoulders and ramp exits and entrances to obtain adequate rest (Garber et al, 2004). Existing research suggests that the ability of vehicles to accelerate safely into the traffic stream from their parked position is limited. Further, parked vehicles tend to conflict with moving vehicles.

A report by Federal Highway Administration (FHWA) (2002) classified factors affecting truck parking along a corridor as follows:

- Engineering factors – including quantifiable measures such as truck travel time, average annual daily traffic, and peak hour factor.
- Truck driver behaviour – time spent resting or at home, time spent loading and unloading or time spent at the shipper or receiver.
- Regulations – working hours of freight drivers parking facilities that are unguided.
- Other factors − proximity to other parking facilities that may absorb demand, ratio between long and short haul and proximity to distribution centres that may affect staging.

2.3.2.1 Estimation of Parking Supply

Garber & Wang (2005) conducted a study to identify rest areas where there was a greater demand for nighttime truck parking than there were available spaces and to document the frequency of this occurrence. Further, they introduced a methodology for estimating required number of truck parking spaces along Minnesota Interstate rest areas. The supply in this model is calculated as follows:

(a) The Minnesota Department of Transport (MnDOT), Model

$$NTSPACES = \frac{ADT \times P \times DH \times D_t \times PF}{VHS} \qquad \textit{(Eqn 3.1)}$$

where:

NTSPACES = number of truck parking spaces required,

ADT = average daily traffic with access to the rest area,

P = total percentage of mainline traffic stopping at rest area,

DH = design hour usage; the design hour compares the design hourly volume, usually the 30th to 50th highest hourly volume, to the annual ADT, producing a factor that predicts a peak usage average-hour situation,

D_t = percentage of truck parking spaces,

PF = peak factor; this is the ratio of an average day of five summer months to average day of year, and

VHS = number of vehicles parked per hour per space.

(b) The Virginia Department of Transportation (VDOT) Model

The Virginia Department of Transportation (VDOT) further refined the Minnesota model whereby the percentage of mainline traffic entering the rest area was increased from 12 to 14 percent. Further, design hour usage ratio was decreased from 0.15 to 0.10 if the ADT exceeded 12,500 vehicles.

The following can be observed from the MnDOT/VDOT study:

- The model estimates truck parking spaces for resting requirements to address driver exhaustion and overnight requirements;
- The model does not consider truck hours of service required or truck parking durations;
- Many other non-traffic factors that may affect demand such as location, lighting, security, food facilities and consequently, parking spaces are not considered in the study.

(c) McShane Model

McShane et al (1990) defined parking supply in terms of how many vehicles can be parked during the period of interest in a model as follows:

$$P = \left(\frac{\sum_n N \; x \; T}{D}\right) x \;\; F \qquad (Eqn\ 3.2)$$

where:

P = parking supply expressed in number of vehicles (veh)

N = number of spaces of a given type and time restriction

T = time that N spaces of a given type and time restriction are available during the study period expressed in hours (hr.)

D = average parking duration during the study period (hr./veh)

F = insufficiency factor to account for turnover. The values range from 0.85 to 0.95 and increase as average duration increases.

This model does not consider the average daily traffic, truck driver behavior or other factors that may affect parking. However, it brings the parking duration into consideration and may be used to supplement the Garber model shown in Equation 3.1.

From the analysis of the average parking duration, McShane (1990) displayed that the data involved computations from field studies including:

- Accumulation totals of parked vehicles for each interval
- Duration distribution by classification and interval parked in each space
- Violations comprising of number of vehicles illegally parked either because they exceeded the specified time limit of the space or because they were in unauthorized locations.

The parking duration and parking turnover rate can be modelled as follows:

$$D = \left(\frac{\sum_x (Nx)(X)(I)}{Nt} \right) \qquad \textit{(Eqn 3.3)}$$

$$TR = \frac{Nt}{S \, x \, Ts} \qquad \textit{(Eqn 3.4)}$$

where:

D = average parking duration expressed in hours per vehicle (hr./veh)

N_x = number of vehicles parked for X intervals

X = number of intervals parked

I = length of the observation interval in hours (hr.)

N_{t} = total number of vehicles observed

TR = parking turnover rate (veh/stall/hr.)

S = total number of legal parking stalls

T_s = duration of the study period expressed in hours (hr.)

Establishing the parking durations is an important consideration when determining truck parking requirements to properly provide for the needs of drivers. The parking duration for truck drivers depends on whether they are traveling long or short haul journeys.

2.3.3. Brazil

2.3.3.1 Working Hours

A comparative study carried out in Brazil shows that Act-12619/2012 enacted by the Brazilian government regulates working hours of freight and passenger vehicle drivers, aiming at decreasing the number of accidents caused by fatigue from excessive driving time (Valente et. al, 2015). According to this law, a truck driver is prohibited from driving continuously for a period longer than four hours. Thereafter, the driver must rest for at least 30 minutes, although there is a grace period of up to one hour for allowing the driver to find an adequate and secure resting site. Moreover, the driver must rest for 11 hours within a 24-hour period, which may be divided into two periods: a 9-hour one and a 2-hour one if these occur on the same day. It was also recommended that drivers avoid working overnight to maintain the natural psychological rhythm in line with the stipulated regulations.

A proper understanding of working hour regulations allows proper siting and provision of truck parking rest stations. It also enables decision makers to properly define the considerations necessary for providing adequate truck parking facilities.

2.3.3.2 Long and Short Haul Trips

The Brazilian case study above is based on a model adopted by the FHWA, which has different provisions for vehicles that cover long and short distances including the kind of preferred stopping places. For vehicles that cover long distances and do not have a preferred stopping place, the average truck-hours of travel per day (THT) is estimated using the following parameters, as posited by Coleman (2002): the percentage of commercial trucks in the total number of vehicles (P_t); the annual average daily traffic (AADT); the length of the roadway segment (L) and the average speed of the trucks (S):

(d) The Brazilian Model

$$THT = P_t \times AADT \times \frac{L}{S} \qquad \textit{(Eqn 3.5)}$$

Thereafter, the following parameters are estimated: the average stop time for each driving hour for long-haul drivers ($T_{DRIVING}$); the time at home for long-haul drivers (T_{HOME}); the loading and unloading for long-haul drivers ($T_{LOAD/UNLOAD}$); the time at shipper/receiver for long-haul drivers ($T_{SHIPPER/RECEIVER}$) - this last term refers to the average stop time per hour throughout the daytime with a purpose other than resting. With these parameters, the estimated average parking time per truck-hour of travel (P_{avg}) is calculated:

$$P_{avg} = \frac{\left(8d \times \frac{24h}{d}\right) - T_{DRIVING} - T_{HOME} - T_{LOAD/UNLOAD} - T_{SHIPPER/RECEIVER} + \frac{5min}{60min}}{T_{DRIVING}} \qquad \textit{(Eqn3.6)}$$

The simplified demand model, (D), is based on the total THT and the average parking time per truck-hour of travel, P_{avg}:

$$D = THT \times P_{avg} \qquad \textit{(Eqn 3.7)}$$

The following can be noted from this study:

Truck-hours of travel per day (THT) is an important consideration in this study and may be used as a dependent variable for determining the truck parking requirements.

This model considers the time spent at home, the duration spent at the shipper or receiver of goods and the time spent loading and unloading the truck. This is important in the analysis, given that the truck driver may also get to fulfil the regulations on hours of service (HOS) while resting in these areas. The reliance on the calculation of probability distributions for the travel and rest times is labor intensive and time-consuming.

Table 2.2: A Summary of Case Studies

	NAME & YEAR	STUDY	STRENGTHS	WEAKNESSES
International Studies				
1.	Montufar Associates (MA) (2009) Canada	Truck Parking Needs at Rest Areas: Environmental Scan	Estimates the supply and demand for truck parking on Saskatchewan National Highway System (NHS) using a corridor-based approach Highlights the importance of stakeholder involvement	This is a supply and demand assessment of existing facilities and may not be applicable to highway parking requirements
2.	Rodier et.al (2007) USA - California	Commercial vehicle parking in California- Exploratory evaluation of the problems and solutions	Estimated truck parking supply and demand in California for both private and public rest areas Projected parking demands up to 2020 Hypothesized on reasons for truck parking shortages and factors affecting truck parking estimates	Since this was exploratory research, the study did not provide a framework for estimating truck parking demand
3.	Gaber et al. (2005) USA	Adequacy of parking facilities	Revealed that shortage in truck parking facilities caused drivers to violate hours of service regulations Gives insight on considerations necessary during programme and project preparation for provision or upgrading of truck parking facilities	Does not provide a framework for modelling truck parking requirements
4	Garber and Wang (2004) Virginia Interstate Highways VDOT	Final report: Estimation of The Demand for Commercial Truck Parking	Compared provision of truck parking by both public and private entities Highlights factors affecting demand for truck parking Considers independent variables to be incorporated in facility design	Does not consider driver hours of service Other non-traffic factors not considered
5.	Federal Highway Administration (FHWA) (2002)	Model Development for National Assessment of Commercial Vehicle Parking	Highlights the factors affecting demand for truck parking Considers independent variables to be incorporated in facility design	Does not make consideration for long/short haul distances Does not make considerations for parking duration and turnover
6.	The Minnesota Department of Transportation	Commercial truck usage night-time	Reported shortage of overnight truck parking in public rest areas	Does not consider daytime parking requirements

	MnDOT (1998) Minnesota	parking demand analysis		Does not consider long/short haul distances
Kenyan Studies				
7.	Njuguna P.G (2015)	Availability of Truck Parking Facilities in Kenya: A case study of Mlolongo Town	Provides a view of the truck parking situation at Mlolongo Obtains qualitative data on why truck drivers are park around the weighbridge station	Data collected was very minimal Does not provide a framework for estimation of truck parking demand
8.	Odula V. (2016)	Assessment of Operations of weighbridges in Kenya: A case study of Gilgil station	Quantifies the service and waiting time at Gilgil Weigh Station	Does not provide tentative information on the existing parking situation at Gilgil

Source, Author 2019

2.4 MODEL ADAPTATION

Forecasting models of expected truck traffic are an essential prerequisite for short- and long-range planning and for determining the amount and timing of capital investment on physical facilities. This thesis examines and adopts both subjective and analytical forecasting methods to establish travel demand related to the overall level of changes in observable characteristics at the Athi River Weighbridge Station. This section provides an overview of the potential suitability of models that can be implemented in the analysis of truck parking facility requirements at the Athi River Weighbridge.

2.4.1 Forecasting

Transportation is modelled on three levels, Macroscopic, Mesoscopic and at the micro level, microscopic forecasting models are considered for travel demand at the local level in the Highway Capacity Manual (HCM), 2010. This assumes that a proportion of the large-scale activity for national or regional demand is assigned to the local level. Consequently, the end results remain relatively constant overtime, and are referred to in the step-down model equation defined as:

$$E_i = M_{ij} \cdot M_{js} \cdot M_{sn} \cdot E_n \qquad (Eqn\ 3.8)$$

where

E_i = Truck arrivals destined to Athi River Weighbridge

M_{ij} = Percent market share for weighbridge station i of scheduled corridor truck haulage in Kenya and landlocked East African region j

M_{js} = Percent market share for East African region j of total Kenyan markets

M_{sn} = Percent market share of Kenya s of the total East African market

E_n = Total scheduled imports/haulage in Kenya

A drawback of this model is that local, regional, and national economic growths are static considering that rapidly growing areas attract more traffic. Arguably, the model approach is subjective and can only be satisfactory under conditions of limited or constant growth. The model's success rate therefore diminishes under complex situations or for long range forecasting.

2.4.2 Microscopic Forecasting by Multiple Linear Regression Analysis

This study will conduct parking demand forecasting through the statistical tool, multiple linear regression, which is used for explaining the relationship between two or more independent variables and a continuous dependent variable. The dependent variable is defined as the seasonal peak parking demand expressed as the number of parking spaces required by users at the *Athi River* Weighbridge. Likewise, the independent variables are the measurable factors affecting parking demand. The following equation by McCarthy (1969) was adopted for this study:

$$Y_p = a_1X_1 + a_2X_2 + a_3X_3 + \dots\dots\dots + a_nX_n + U \qquad \textit{(Eqn 3.9)}$$

where

Y_p = Number of truck trips

$X_1, X_2, X_3 \dots X_n$ = Independent variables

$a_1, a_2, a_3 \dots a_n$ = Co-efficient of independent variables

U = Disturbance constant

This model assumes that all the variables are independent of each other and that there exists a linear relationship between the dependent and independent variables. The equation also assumes that all the variables are continuous and normally distributed.

The advantage of this model is that it offers a strong and sophisticated prediction and examination of the research hypotheses using multiple independent variables that affect the dependent variable, whilst avoiding the use of non-optimal combinations of predictors. It also establishes multi-causal relationships between predictors and criterion thereby displaying a link between various correlation and analysis of variance models. Further, the relative influence of predictor variables on dependent variables can be clearly observed and any anomalies in the model can be easily identified.

However, multiple regression analysis is often inappropriately used to model non-linear relationships and sometimes has a low predictive accuracy when complex independent variables need to be analysed. According to one author, regression analysis is limited to only providing numerical output, with the regressed coefficients becoming less reliable as the degree of correlation between independent variables increases (Kadiyali, 1987). This implies that if there is a high degree of correlation between variables, then there is a problem of multicollinearity. Attention is drawn to the use of only one set of the independent variables to make for a credible estimate.

2.4.3 Model for Estimating Peak Parking Demand

To estimate the parking demand for the busiest scenario, seasonal parking factors can be applied to the base parking demand in order to obtain the peak parking demand. A model for predicting peak parking needs (Weant et. al. 1990) may be estimated as follows:

$$D = \frac{N.K.R.P.pr}{O} \qquad (Eqn3.10)$$

Where D = Peak parking demand, spaces

N = Size of activity measured in appropriate units (floor area, employment, dwelling units or other appropriate land use parameters

K = Portion of destinations that occur at any one time

R = Person-destinations per day (or other time period) per unit activity

P = Proportion of people arriving by truck

Pr = Proportion of persons with primary destination at the designated study location

O = Average vehicle occupancy.

Upon establishing the peak parking demand, Table 2.3 can be used in design in order to determine the parking space per unit to be provided in suburban settings, based on the land use of the location.

Table 2.3: Recommended Parking Zoning Requirements in Suburban Setting

		Parking Space per Unit	
Land Use	Unit	Peak Parking Demand	Recommended Zoning Requirement
Industrial General	Employee	0.60 – 1.00	1.0 + $1.0/_{1,000}$ sq. ft GFA
Storage, wholesale or utility General	GFA 1,000 sq. ft.	N/A	0.50 + required spaces for office or sale areas

Source: Weant et al, 1990

Whereas this model would be useful in the provision of parking space for private rest areas, or for shipper/receiver determination of truck parking requirements, it may prove challenging in *Athi River,* because the consideration is for vehicles on transit and has a wide range of users.

2.4.4 Capacity Utilization Models

These models identify the services and facilities that affect the utilization of truck parking spaces at rest areas. VDOT (2005) suggests that demand related factors affecting rest area usage by trucks include average daily traffic volume (ADT), percentage of truck traffic expressed as a percentage of ADT, distance from previous rest area or proximity of rest area to a major intersection. Similarly, supply related factors affecting the utilization include:

- Total number of available truck parking spaces
- Type of parking space (parallel, diagonal)
- Available facilities such as security, lighting, rest rooms
- Special parking rules

An econometric model by VDOT (2005) was developed to estimate the individual impact of each of the above factors on the utilization of parking spaces:

$$CU = b_0 + b_1ADT + b_2TADT + b_3D_{PRV} + b_4D_{INT} + b_5SP + b_6TYPE + b_7Z + b_8REQ + e_i \qquad (Eqn\ 3.11)$$

where

CU = Utilization of rest area parking spaces (dependent variable)

ADT = One-way average daily traffic

$TADT$ = Trucks as a percentage of ADT

D_{PRV} = Distance from the previous rest area

D_{INT} = Distance from a major intersection

SP = Total number of available parking spaces

$TYPE$ = Type of parking space available

Z = Matrix of all the facilities provided at the rest area

REQ = Any time limit rules related to parking

b_0 = Constant term that captures the average effect of all omitted variables

$b_1 \ldots b_8$ = Individual coefficients on the independent variables

e_i = Error term

The dependent variable in the model, capacity utilization (CU), is a dummy variable with a value of 1 if the rest area parking capacity is typically full or overflowing or 0 if it is typically not crowded. Many independent variables depicting the characteristics of rest areas also had to be represented as dummy variables.

This model presupposes the availability of parking facilities and rest areas along a corridor, and therefore is only relevant up to the second independent variable on a link without such installations.

2.4.5 Queuing Processes in Traffic Flow

Queuing theory originally developed by Erlang (1909) has found widespread application in the problems of highway traffic flow. In any queuing process, arrivals are processed through the existing service configuration. Of significance to this study is how trucks enter the system, amount of time spent waiting for the service and the way they are served. The queue process discipline is based upon a first come first served basis (see Figure 2.1 below).

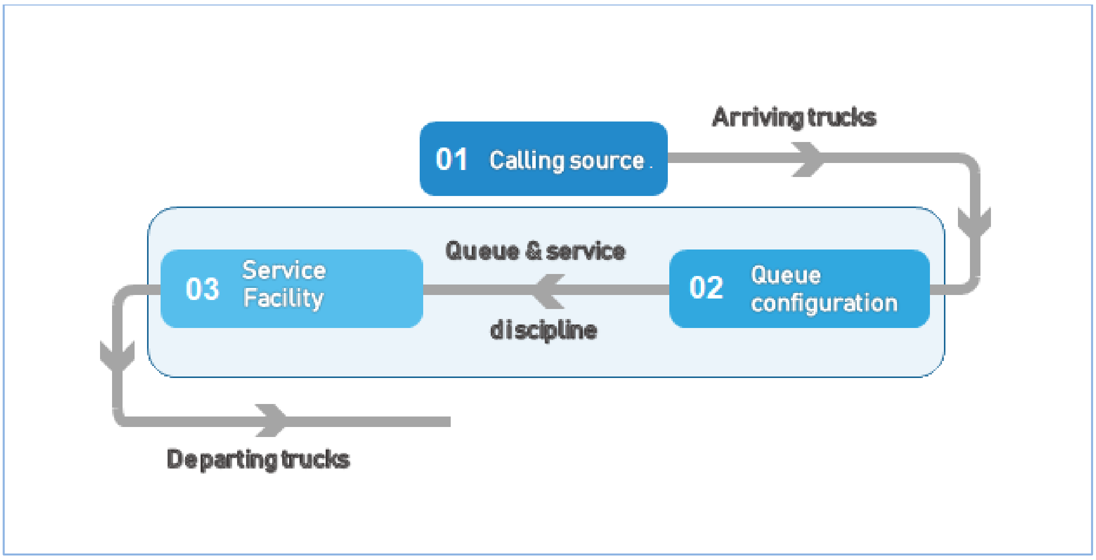

Figure 2. 1 Schematic Representation of the Queuing Process

Source: Author, 2018

Queuing models are identified by a nomenclature of A/B/C/D/E illustrated by Kendall (1953) as shown below:

A: Arrival distribution measured by arrival rate or inter-arrival time. This can either be:

M: Poisson distribution or Negative exponential,

D: Deterministic times or Constant Value,

K: Erlang Distribution,

G: General distribution with known mean and variance.

B: Service time distribution, which can also be described as either M/D/K/G as above

C: Specification of number of servers — ‘s’

The last two components, D and E, of the nomenclature are usually not used but may be used to represent the maximum number allowed in a queuing system and the customer population respectively. An example of the use of this notation depicts a queuing model with Poisson arrival and service rates with three servers described by M/M/3.

Five key relationships provide the basis for queuing formulations and are common for all infinite-source models (Vandael et.al. 2000):

1. The average number of customers being served is the ratio of arrival to service rate.

$$r = {}^{\lambda}/_{\mu} \qquad \textit{(Eqn 3.12)}$$

2. The average number of patients in the system is the average number in line plus the average number being served.

$$L = L_q + r \qquad \textit{(Eqn 3.13)}$$

3. The average time in line is the average number in line divided by the arrival rate.

$$W_q = {}^{Lq}/_{r} \qquad \textit{(Eqn 3.14)}$$

4. The average time in the system is the sum of the time in line plus the service time.

$$W = W_q + {}^{1}/_{\mu} \qquad \textit{(Eqn 3.15)}$$

5. System utilization is the ratio of arrival rate to service capacity.

$$\rho = {}^{\lambda}/_{s\mu} \qquad \textit{(Eqn 3.16)}$$

where r = average number of customers being served

λ = arrival rate

μ = service rate

L_q = average number of customers waiting for service

L = average number of customers in the system

W_q = average time customers wait in line

W = average time customers spend in the system

$1/\mu$ = service time

ρ = system utilization

2.4.5.1 The M/M/1 Model

This method considers that the customer arrival rate follows the Poisson distribution with rate parameter (λ) and queue discipline of first-come, first-served. The service time also displays negative exponential distribution. Arguably the simplest model, this system considers only one server. Notably, the length of queue can be as endless as the demand for a given facility.

$$L_q = \lambda^2 / \mu(\mu - \lambda) \qquad \textit{(Eqn 3.17)}$$

$$P_o = (1 - \lambda)/\mu \qquad \textit{(Eqn 3.18)}$$

$$P_n = P_o(\lambda/\mu)^n \qquad \textit{(Eqn 3.19)}$$

$$P_n = (1 - \lambda)/\mu \; (\lambda/\mu)^n \qquad \textit{(Eqn 3.20)}$$

where λ = arrival rate

μ = service rate

L_q = Length of the queue

P_o = Probability of no arrival

P_n = Probability of n trucks arrival

The steady state probability that exactly *n* trucks are in the system can be calculated as:

$$P^n = (1 - \rho)^n \qquad \textit{(Eqn 3.21)}$$

This model is applicable towards simple systems such as weighbridge queuing system and provides high levels of accuracy even when a non-stationary arrival rate is presented. Parameters such as the arrival and service rates, utilization and length of the queue are easily derived in this method. However, when balking and reneging are allowed, they affect the accuracy level of the model.

2.4.5.2 Queuing at the Weighbridge (M/M/1)

Athi River Weighbridge Station has one server (weighbridge) per queue; therefore, M/M/1 shall be adopted for the design of a suitable weighbridge capacity.

The major determinant of parking demand at the weighbridge location is vehicle accumulation, dictated by the service efficiency for the arrivals. This includes the circulation within the weighing area and the merging configuration for the departing trucks to join the highway.

2.4.6 Matrix of Models in Determination of Truck Parking Requirements

The Truck Parking Demand models are assessed to determine their application and suitability at a microscopic level, based on the following considerations:

1. Does the model derive truck parking demand on a transport corridor?
2. Is the volume of traffic represented as a variable?
3. Is the model representative of the situation at *Athi River* Weigh Station?
4. Does the model consider operational factors at location of evaluation?
5. Does the model consider the weighting of the factors affecting parking demand?

Table 2. 4: Matrix of Models in Determination of Parking Requirements

Item	Model	1.	2.	3.	4.	5.	Remarks (below)
1.	Multiple linear regression model by McCarthy (1969)	✓	✓	✓	✓	✓	i.
2.	Capacity Utilization Model by Apogee developed for Minnesota DOT (Mn-DOT)	×	✓	×	✓	×	ii.
3.	Cu Econometric	×	✓	×	✓	×	iii.

Source: Author, 2018

Remarks

The multiple linear regression model by McCarthy can assess the truck parking demand for both short and long-haul journeys. It considers the weightage of the independent variables on the total demand. It is suitable for the determination of the parking demand at the *Athi River* Weigh Station.

The Apogee model is a capacity utilization assessment related to a network of parking facilities and rest areas within a highway network. It assumes that existing parking and utilities are in place and in use, which is not the case at the *Athi River* Weigh Station.

Similarly, the econometric model is a capacity utilization model which is an economic assessment for informing decision making on facility investment. This model is suitable for determination of parking demand at the *Athi River* Weigh Station.

2.4.7 Matrix of Models in Choice of Operational Efficiency Assessment

The models below help in guiding the optimization of facility design to inform investment decision making using the following:

1. Is the model relevant to parking facility design?
2. Is the model related to parking facility operational standards?
3. Is the model relevant to the situation at Athi River Weigh Station?
4. Does the model guide on the economic viability of investment over the project lifecycle?

Table 2. 5: Matrix of Models in Choice of Operational Efficiency Assessment

Item	Model	1.	2.	3.	4.	Purpose
1.	Macroscopic Forecasting	✓	✓	✓	✓	i.
2.	Queuing Models (M/M/1)	✓	✓	✓	×	ii.

Source: Author, 2018

Purpose

The Microscopic model forecasts future traffic at the local level based on assumptions on national and regional demand. It may be used to model truck arrivals at the *Athi River* Weighbridge. The operational standards are influenced by the queue length expected to access th e facility, making it suitable to demonstrate operational situations in *Athi River* Weighbridge. Additionally, performance measures including travel time, speed and delay per vehicle are significant in the choice of optimal efficiency and design of the Northern Corridor Road weighbridge parking amenities.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Data Sources and Collection Methods

This chapter outlines the research methodology of the study, as well as the specific field research methods employed by the author. This includes the data collection, interviews, field observations and photo surveys. The primary objective of the data collection was to determine the considerations necessary for providing adequate truck parking facilities at the *Athi River* Weighbridge Station, and to facilitate the development of a suitable model for future assessment of parking studies, by employing the multiple linear regression analysis method.

3.2 Data Sources and Collection Methods

In order to satisfy the specific objectives of the study, quantitative research was carried out. Expressly, traffic surveys were utilized for descriptive, explanatory, and exploratory research. The study also reviewed existing literature and further information was collected through administration of driver questionnaires, capturing of aerial images and consultation of the web-based geographic program Google Earth™. Field observations in form of volume counts and parking and queuing surveys were conducted by the researcher. Also included were field measurements reflecting the physical dimensions and condition of the existing weigh bridge station. Figure 3.1 illustrates the exact location of the weighbridge and how it relates to the larger *Mlolongo* study area.

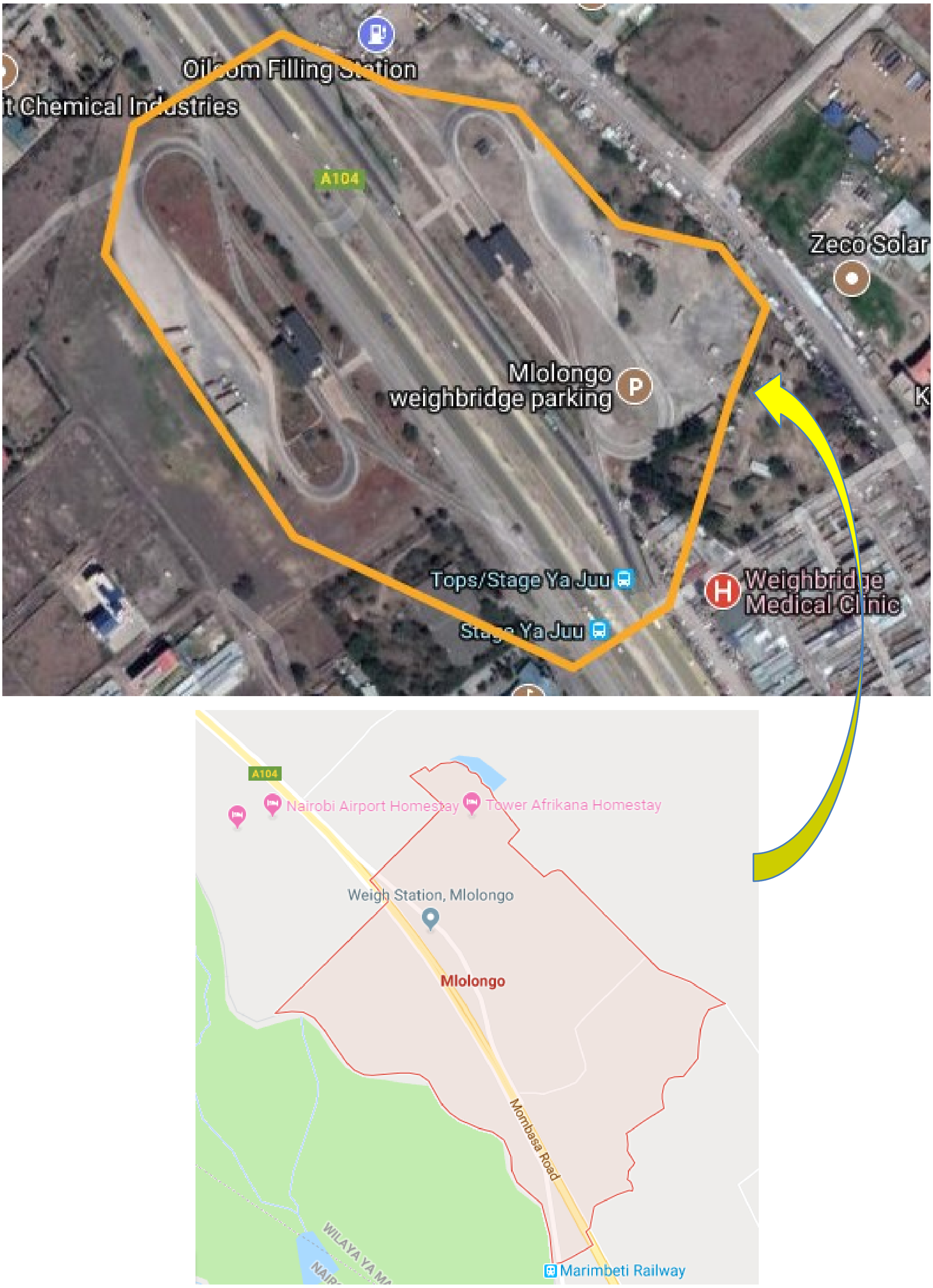

Figure 3. 1 Study area at *Mlolongo*

Source: Google Maps, 2018

According to Schrank D. and Lomax T. (2009), the focus of performance measures related to congestion at weighbridges includes:

i. Duration - defined as length of time the facility is affected by congestion;
ii. Extent - being the number of people and geographical location affected by congestion;
iii. Intensity – representing severity of congestion or more candidly, the actual trip in relation to expected trip experience; and
iv. Reliability – described as variation of the first three dimensions of a, b, and c.

These measures formed the basis of the observational studies conducted. At this stage, the materials, documents, and personnel needed for data collection were mobilized and the management of *Athi River* Weighbridge Station was notified of the intent to collect data on their premises.

3.2.1 Review of Existing Literature

Secondary data was collated, reviewed, and analyzed from sources such as subject relevant literature, journals, internet, published works, master plans, manuals, and existing surveys. Other sources included statistics from Japan International Cooperation Agency (JICA), Nairobi Metropolitan Services Improvement Project (NaMSIP) and relevant transport authorities.

3.2.2 Field Observations and Measurements

Several site visits were conducted to evaluate truck parking availability, existing truck parking trends around Athi River Weighbridge Station and to identify the operational and layout constraints in relation to parking requirements. Consequently, due consideration was given to the following issues:

i. Abutting land use at the study area, and its ability to provide adequate parking facilities (See Figure 3.1 and Figure 3.2)

Plate 3.1 Area around Athi River Weighbridge (A3)

Source: Google Maps, 2018

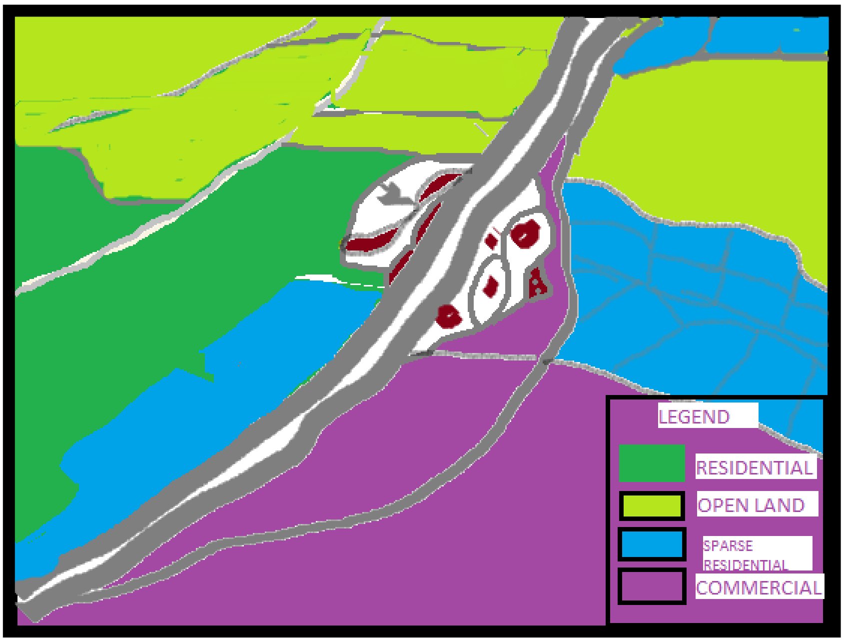

Figure 3. 2 Land Use around Athi River Weighbridge (A3)

Source: Author, 2017

ii. Existing parking facilities, roadside amenities and their condition at *Athi River* Weighbridge;

iii. Truck parking patterns, and how parking necessities are currently met and thus establishment of the effects of the weigh station on parking requirements which are characterized by increased congestion at the study area. This includes truck parking supply information such as facility layout descriptions and total parking spaces, the number of available spaces, parking duration and limits, as well as facility ownership (public/private);

iv. The operational procedure at the *Athi River* Weighbridge; and

v. Traffic circulation in and out of the weighbridge including traffic flow on the Mombasa Road section next to the weighbridge.

3.2.2.1 Reconnaissance Visit

A reconnaissance of the study area was conducted on 27th September 2018. Notably, the study boundaries were adjusted, because truck parking was widely distributed on both sides of the dual carriageway. Also, the parking accumulation survey could not be conducted using the conventional entry and exit analysis, because of the new HSWIM screening device. Consequently, dividing the study area into zones was selected as the most appropriate way to represent the varying truck parking requirements of the area.

The study observed that the holding areas were only being utilized for the accommodation of non-compliant vehicles at the weighbridge. This meant that drivers looking to rest or access amenities were not authorized to park in the holding areas. Other restrictions such as the access to bathrooms and restrooms at the station were applied, limiting the use of the facilities to drivers who had trucks at the holding areas, to include the weighbridge employees.

Currently, the vehicle holding area at the Mombasa bound station has a capacity of 20 trucks and is paved without markings. Due to higher truck volumes at the Nairobi bound station, the vehicle holding area was upgraded to provide for another 20 trucks, though the additional parking area remains unpaved. The parking spaces are regulated by private security who direct the drivers to angle park. Additionally, each station has a parking provision for 10 vehicles, which is used by employees and guests at the stations. At the time of the reconnaissance, there had been no reported cases of theft or loss of goods for vehicles held in the yard. The stations are manned by both private security and armed police officers and are well monitored through Closed Circuit Television (CCTV) surveillance.

The weighbridge is owned by the Kenya National Highways Authority (KeNHA), which subcontracts its operations to a private company Société Générale de Surveillance (SGS). Vehicles that have been impounded and held at the yard can be cleared between 1-2 hours following agreement to pay the specified penalties by KeNHA. However, if the fine is challenged, the vehicles can be cleared after 1-2 days pending a court ruling. The vehicles are allowed to stay up to 3 days, after which a daily charge of KShs. 2,000 is attracted for continued parking in the yard. Checkpoint locations were identified and the data from this visit was used to refine data collection tools.

3.2.3 Data Collection Resources

Several data collection materials and forms were designed for the purposes of this study as listed below:

i. Sample sheets;
ii. Parking accumulation sheet;
iii. Parking duration sheet;
iv. Truck driver questionnaire; and
v. Queuing studies sheet.

Transportation vehicles and cameras were also secured as equipment for data collection. A total of twenty-seven individuals, were enlisted to assist with the collection of data. Four supervisors spearheaded the efforts of each of the data categories described above; seven enumerators were responsible for the parking duration studies; nine enumerators were responsible for parking accumulation counts; four interviewers undertook the administration of truck driver questionnaires; two enumerators were responsible for queuing studies; and there was one driver.

On 4th October 2018, a training session was held with the personnel to sensitize them on the importance of each of their roles, the objectives of the study and the procedures to be used in data collection. Thereafter, a pilot study was conducted on 5th October 2018 to serve as orientation, and to test the zoning plans and the ease of recording the data required.

3.2.4 Traffic Surveys

According to (Garber, 2005) a survey on weighbridge queuing system categories should be based on the following conditions:

i. Truck arrival patterns;
ii. Truck departure patterns;
iii. Truck service patterns; and
iv. Truck queue disciplines.

The research sought to establish truck arrival pattern options that suited conditions at the *Athi River* Weighbridge:

- At equal time intervals – that is, whether trucks arrive at a uniform or deterministic rate, forming a uniform distribution;
- At exponentially distributed inter-arrival times − whether trucks exhibit Poisson or Markovian distributed arrivals forming a negative exponential distribution; and
- At inter-arrival truck times which follow a general probability distribution.

Furthermore, the investigation focused on whether there was a likelihood of the maximum queue length spilling back towards upstream links and potentially affecting other vehicle traffic operations upstream or downstream. To this end, various traffic surveys were carried out between 8^{th} October and 11^{th} October 2018. A total of 15-hour counts were conducted on Monday 8^{th} and Wednesday 10^{th} respectively, and likewise, a total of 19-hour counts were conducted on Tuesday 9^{th} and Thursday 11^{th}. The traffic surveys were conducted to include the following:

(a) Volume Counts

Traffic volume counts were obtained from daily logs recorded at the *Athi River* Weighbridge databank, on the Mombasa Road section next to the *Athi River* Weighbridge and on the auxiliary lanes, measured from the point of traffic diversion into the weighbridge. This helped determine the vehicular demand around the weighbridge.

(b) Travel Demand surveys

The travel demand surveys provide a more detailed picture of travel patterns and choices of drivers. They included information on trip origin and destination, trip purpose and trip frequency.

(c) Parking Demand Surveys

Parking demand surveys were conducted to determine the following:

i. *Parking accumulation* – number of vehicles at the *Mlolongo* study area;
ii. *Parking load* – space/hour usage of the parking facility, measured in veh/hr./day;
iii. *Parking duration* – length of time vehicles remaining in parked condition, expressed in hours; and
iv. *Parking volume* – actual number of vehicles parked at the *Athi River* Weighbridge Station in a day, expressed as veh/day.

Plate 3. 1 Data Collection Personnel at Athi River

Source: Author, 2018

(d) Queuing Surveys

Queuing surveys were carried out by recording the time taken by a truck from the time of entry into the weighing scale, to the time of exit. The results were used to determine truck dwell time and assess the operations at the weighbridge using queuing models which were developed according to Highway Capacity Manual (HCM), 2010.

3.2.5 Interviews

(a) Truck Driver Interviews

Curated questionnaires were administered to truck drivers to determine their views on the operations at *Athi River* Weighbridge. This included their perceptions on challenges that arise because of these operations.

(b) Key Informant Interviews

Key informant interviews were carried out, in the form of semi-structured questionnaires to select respondents involved in the operational procedures at *Athi River* Weighbridge, such as the engineers in charge of axle load control and representatives from the Kenya Transporters Association (KTA). The focus was on eliciting responses on key issues revolving around current operations at the *Athi River* Weighbridge and the measures which need to be put in place to improve its operations.

3.3 Zoning of Study Area

The study area was divided into zones to depict different characteristics of the complex *Athi River* Weighbridge parking requirements (See Figure 3.3).

Figure 3. 3 Zoning of the Study Area

Source: Google Maps, 2011

Zone A and B are along the Old Mombasa Road, passing directly inside *Mlolongo* Town, while Zone C begins after the Mombasa bound weigh station and ends at the footbridge at *Mlolongo*.

Zones D, E and F lie along the Nairobi bound side of the carriageway, with F being nearest to the footbridge, D stretching to the weigh station and E lying downstream off the weighbridge.

3.4 Data Transcription and Reduction

Three supervisors from the data collection team transcribed the data collected on site, using Microsoft Excel and Google Form workbooks for logging accumulation data, duration data and information from the questionnaires. These were divided into different zones for analysis of individual and aggregate characteristics of the parking areas.

Finally, the data was reduced to remove outliers and erroneous logs through visual inspection of the trends in the data. Also, in Zone D, it was noted that many buses were parked during a given period. The research team investigated this trend on Thursday 11th October 2018 and obtained bus parking volumes in this zone to determine whether they were to be considered significant when investigating parking requirements in the area. The data was then organized and grouped per zone, for each of the four (4) days of the week.

3.5 Summary

This study utilized both qualitative and quantitative research methods, to better characterize the factors that affect truck parking demand, and to describe a model to estimate this demand. Field interviews with truckers were analyzed and interpreted, to establish the truck drivers needs and preferences. The results provided data that was used to verify some of the assumptions in the model. A modelling approach was employed to determine the aggregate truck parking demand for commercial vehicle parking at the study area. The quantitative diurnal truck parking data was established at an interval and guided by parking utilization on various locations within the *Mlolongo* town ship. The Multi Linear Regression Analysis was used to establish the parking demand model, suited to the location.

3.6 Conceptual Framework

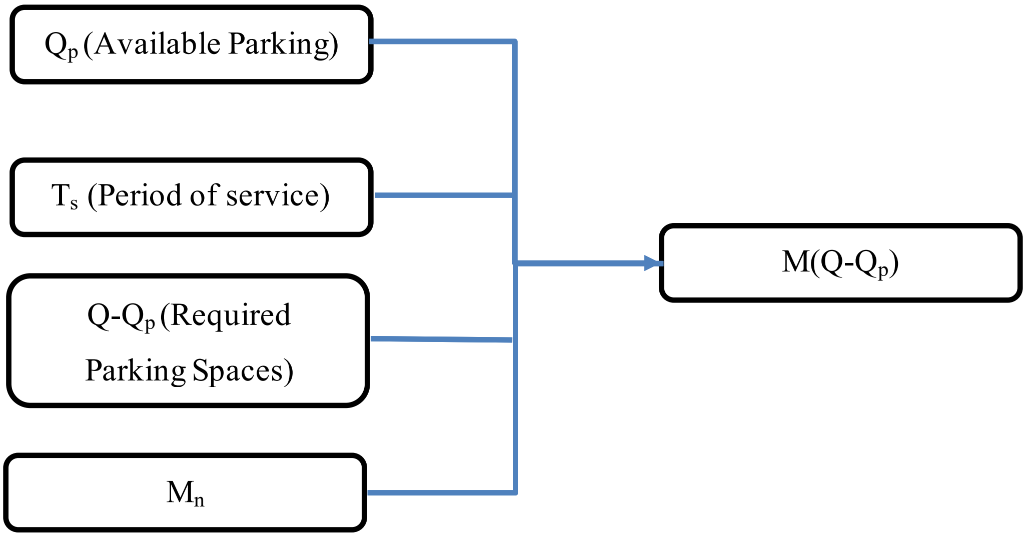

Figure 3. 4 Conceptual Framework

Source: Author, 2018

Where Q_p is the number of parking spaces at the *Athi River* Weighbridge Station.

Q is the measured demand from field studies at the *Athi River* Weighbridge Station.

M_n is the review of several macroscopic models that approximate to the field conditions and

M is the model that closely fits the measured demand.

CHAPTER FOUR: RESULTS, FINDINGS, ANALYSIS AND DISCUSSIONS

4.1 Overview

This chapter presents a truck parking model adaptation using data from a truck parking survey conducted in October 2018. A discussion of the results is included, which consisted of the utilization of a Microsoft Excel Spreadsheet Application for the analysis of surveyed traffic, as well as the calibration of truck parking demand estimates.

4.2 Validity of Data

Data validation was conducted to ensure the accuracy and quality of the data collected. In particular, the researcher ascertained that the sample size obtained reflected the situation experienced by the entire population in Athi River Weighbridge Station, therefore justifying the validity or relevance of the conclusions made at the end of this study. According to Turner et al (1998), the equations used for obtaining the minimum required truck sample sizes are:

$$Sample\ size, n = \left(\frac{t\ x\ c.v}{e}\right)^2 \quad \text{for } n < 30 \qquad (Eqn\ 4.1)$$

$$Sample\ size, n = \left(\frac{z\ x\ c.v}{e}\right)^2 \quad \text{for } n > 30 \qquad (Eqn\ 4.2)$$

where:

t = t-statistic from the student's t-distribution for (n-1) degrees of freedom, and is based on a specified confidence level from equation 4.3 below.

$$t = \frac{\frac{sum(\ min - \max)}{No.of\ zones}}{\sqrt{\frac{sum(min - \max))^2 - \frac{sum(min-))^2}{No.of\ zones}}{(No.of\ zones - 1) * No.of\ zone5}}} \qquad \text{(Eqn 4.3)}$$

$c.v$ = co-efficient of variation, which is the relative variability in travel times observed, expressed as a percentage,

e = relative allowable error in travel time estimate, expressed as a percentage,

z = z-statistic used in place of the t-statistic when sample size is greater than 30. It is obtained from normal distribution curve

Through an iteration process with different sample sizes and estimated coefficients of variations, the equations above were used to develop a table of minimum sample sizes to be used to check data (See Table 4.1):

Table 4.1: Minimum Vehicle Sample Sizes

Traffic Density	Average Coefficient of Variation (%)	Sample Sizes		
		90% confidence, ± 10% Error	95% confidence, ± 10% Error	95% confidence, ± 5% Error
Low to moderate traffic, 15 – 30-minute time period	10	4	5	18
Low to moderate traffic, 1 – 2-hour time period	20	12	18	62
Congested Traffic, 15 – 30-minute time period	25	18	27	96
Congested Traffic, 1 – 2-hour time period	35	34	48	189

Source: Adapted from Turner, Eisele, Benz and Holdener, 1998

The study area's survey parking accumulation and duration data were tested for validity and use of Microsoft Excel filters. Similarly, the data was checked against the minimum sample sizes for a 90% confidence level and ±10% error. Out of the 3,544 samples collected for parking accumulation and duration studies, 98 failed the significance test, making 2.7% of the total number of samples. Consequently, it was recorded that 97.3% of the samples were significant, for a 90% confidence, and ±10% error. From this analysis, the sampled data was found to be reasonably accurate and fit to use for the purposes of the study.

4.3 Results and Findings

4.3 .1 Travel Demand Surveys

Travel surveys provide information on the truck drivers travel patterns and behaviour characteristics, which are essential for the development of travel demand models and in the transportation planning process. A total of 469 surveys were accepted as valid for the purposes of this research, and the following data collected:

(a) Trip Origin: From the 462 respondents who were interviewed, 51% originated from the port of Mombasa, 14 % from *Mlolongo* area, 8% from *Athi River*, 6% from Nairobi, 5% from *Kajiado*; and 5% from *Machakos* respectively. Evidently, the trips predominantly originate from the Port as imports into the Region.

(b) Trip Destination: As part of the survey, the truck drivers were asked to provide the destination of the vehicle trips: 24% of the respondents interviewed stated that they were destined for Nairobi; 17% to Kampala; and 9% to Tanzania respectively. Other popular destinations included *Athi River, Mlolongo, Kisumu, Malaba, Jinja, Rwanda, Congo* and *Sudan* (See Figure 4.1 below). It can be concluded that the inbound logistics are destined for Nairobi.

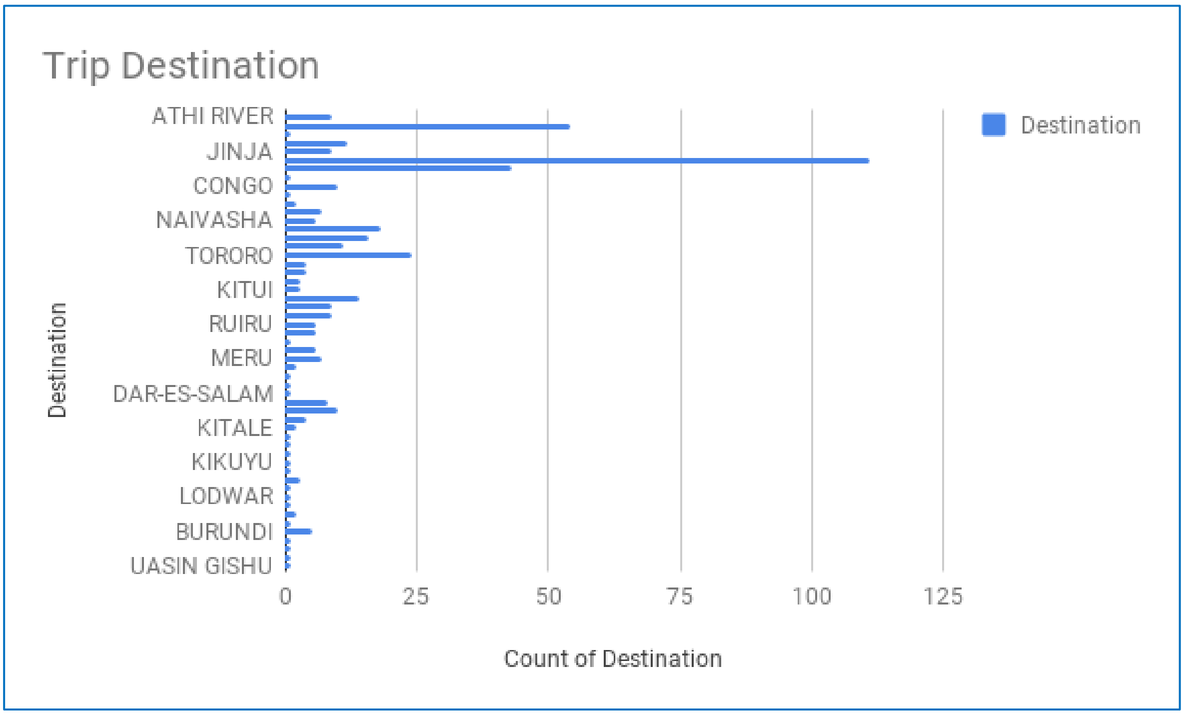

Figure 4. 1 Trip Destination data

Source: Author, 2017

(c) Trip Purpose: When asked what the purpose of their trip was, 95% of the truck drivers interviewed stated that it was for delivering goods or products; while 3 % stated that it was business related. Amongst the other respondents interviewed, 66% were carrying manufacturing goods such as timber and textiles;15% were carrying food products including cooking and agricultural produce; 10% of truck drivers indicated they were carrying hazardous materials such as petroleum, pesticides and LPG; and 7% of the truck drivers indicated that they were carrying wholesale or retail products. Only 2% of drivers did not know what they were carrying, in containerized cargo. Consequently, the study deduced that corridor logistics are mainly industrial.

(d) Trip frequency: To better understand the truck drivers' behaviour and travel patterns, the researchers asked respondents how many times they made trips. Findings revealed that 45% of the respondents interviewed made the trip once or twice a week; 15% made the trip more than once a day; whilst the short haul truckers, representing 14% of the respondents, made this trip every working day of the week. Further, 12% of the respondents interviewed indicated that they made the trip once a fortnight, with 12% making the trip occasionally. This high frequency suggests that the provision of roadside amenities and facilities, are necessary for the benefit of the trucking crew along the corridor

(e) Demographics of the trucking crew: In addition to the travel attributes, the study collected driver-specific information such as age, sex, nationality, and religious affiliation, to help inform the best locations for various strategies. The survey established that 99.1% of the truck drivers interviewed were male, whilst 4 % were female, with the latter more likely to prioritise safety and convenience as important, when parking. Amongst those surveyed, 47% were between the ages of 31-45; 26% between the ages 46-60; and 25% were between ages 23-30 years, respectively. With regards to geographical distribution, 95% of the respondents interviewed were Kenyan, 3% were Ugandan, and 1% Tanzanian. Out of the 202 respondents who provided data on their religious affiliation, 79% were Christian and 21% were Muslim.

(f) Number of crew: More than half of the drivers (59%) reported to be the sole occupant in their trucks, with 38% indicating the presence of an additional occupant (See Figure 4.2).

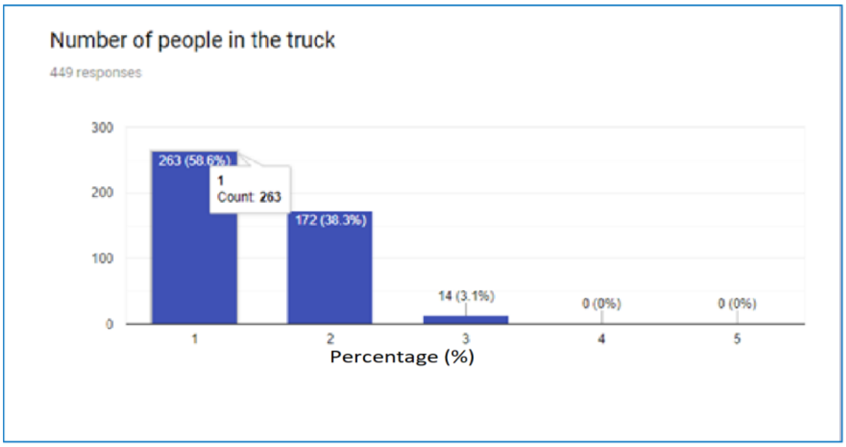

Figure 4. 2 Trip Destination Data

Source: Author, 2017

(g) Travel Duration: Approximately 50% of the survey respondents reported that their entire journey took more than a day. Only 23% indicated that their trip took between 6-24 hours respectively. Fifteen percent of the truck drivers interviewed reported that a trip took between 3-6 hours, whilst another fourteen percent stated that their journey takes between 1-3 hours. This data is a guide on the rest requirements for the freight community. Notably, 39% of the respondents interviewed pointed out that they spent between KShs 200-500 daily on food and refreshments, and between KShs 600-1000 on accommodation.

(h) Purpose for Truck Parking: A myriad of reasons was provided by the freight community, with implications for the parking demand in the Northern Corridor (See Figure 4.3). The most common reason given was the expected congestion and/or traffic volumes at the weighbridge. On the other hand, survey response indicated that 22% of the respondents interviewed, preferred to make long term stops because they required more services (fuel, meal, showers) than rest areas. Additional, 10% of the truck drivers preferred services such as breakdown services, but less often. A minority of respondents interviewed (9%) stated that they were parked in *Mlolongo* because of detention at the weighbridge due to non-compliance. Information gathered from the survey established that the minority (2%) preferred to make long term stops because they required servicing, or they did not stop at all.

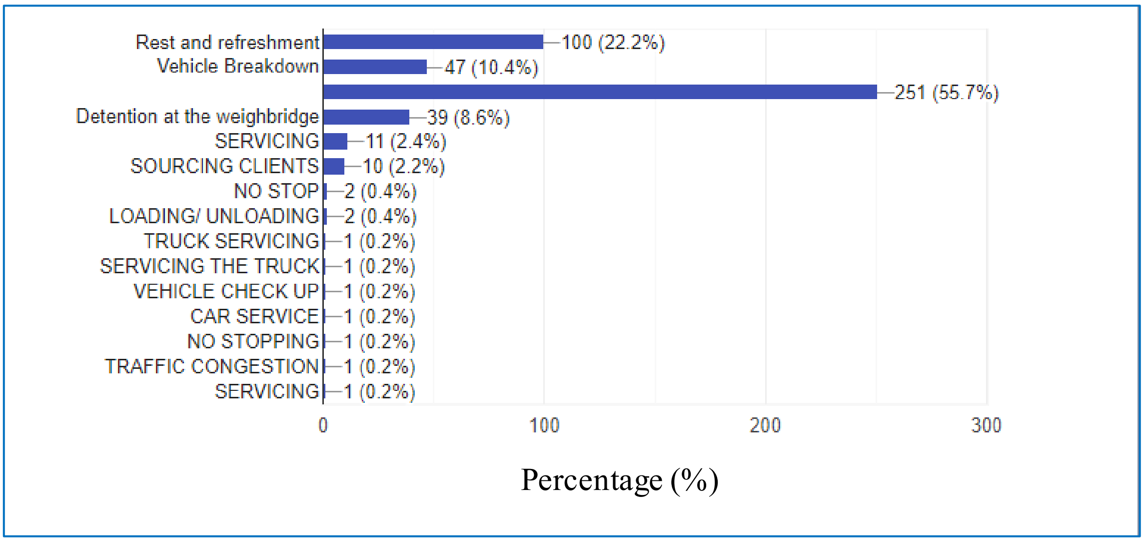

Figure 4. 3 Reasons for Truck Parking

Source: Author, 2017

(i) Service quality rating: It was noted that 46% of the respondents interviewed rated the weighbridge operations as satisfactory, with 40% confirming that the operations were fair. Still, 14% of respondents interviewed pointed out that the quality of the services was bad, while 33% complained of unfair treatment by weighbridge officials, to include cases of corruption. Survey results not only provide an understanding of what is important to drivers, but also provide the list of needs and amenities that have been used as criteria in the evaluation of new or expanded site alternatives.

(j) Preferred hours of arrival: According to those surveyed, most truck drivers (60%) preferred to arrive in *Mlolongo* for weighing during the midmorning hours between 9-12 noon, with only 28% of the respondents interviewed, indicating preference for early morning hours between 4-9am. It was also established that only 9% of respondents interviewed preferred to arrive in the night. These findings suggest that the peak parking utilization period at the study area, is best suited in the late hours of the night, to allow truck drivers to have early access into the weigh station.

(k) Parking utilization: Since the number of parking spaces available, is only part of the parking picture, respondents were asked to rate the parking usability. On average, drivers (75%) preferred to proceed with their trips, immediately after service at the weighbridge. Only 23% of the respondents interviewed preferred to park at a truck stop and take a break. The drivers who rest in *Mlolongo* gave more information on where they typically parked their trucks (See Figure 4.4). Sixty-four percent of respondents preferred to leave their trucks by the roadside, with approximately thirty-one percent indicating that private parking, if made available, would improve the parking situation. Perhaps these respondents would make use of alternative parking areas and park less often in areas not designated for truck parking.

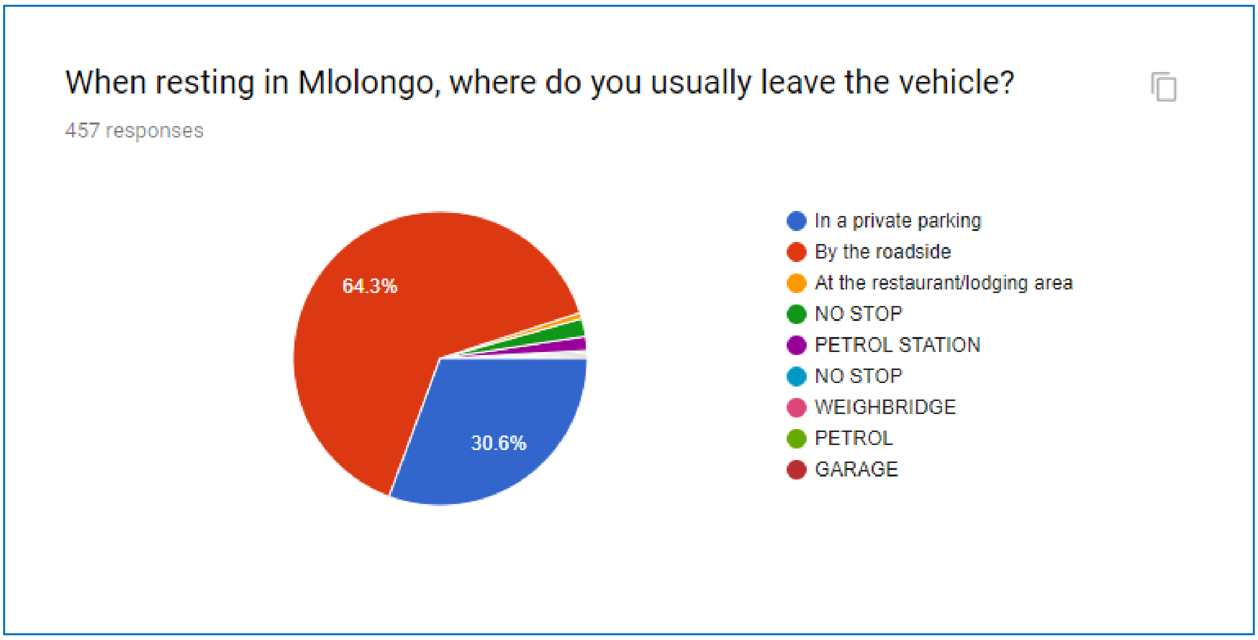

Figure 4. 4 Truck Drivers' Parking Preferences

Source: Author, 2017

(l) Identified Service requirements: To help clarify drivers' parking preferences, the survey asked truck drivers to identify the challenges they faced when parking in Mlolongo. At least 76% of respondents stated security and safety as the main challenge, to include the loss of vehicle parts or goods carried. Ten percent of respondents marked that there were inadequate sanitation services, with only six percent reasoning that access to proper parking was their greatest challenge. Interestingly, 19% of respondents indicated that they would like to have access to medical services at Athi River weighbridge and its environs (See Figure 4.5).

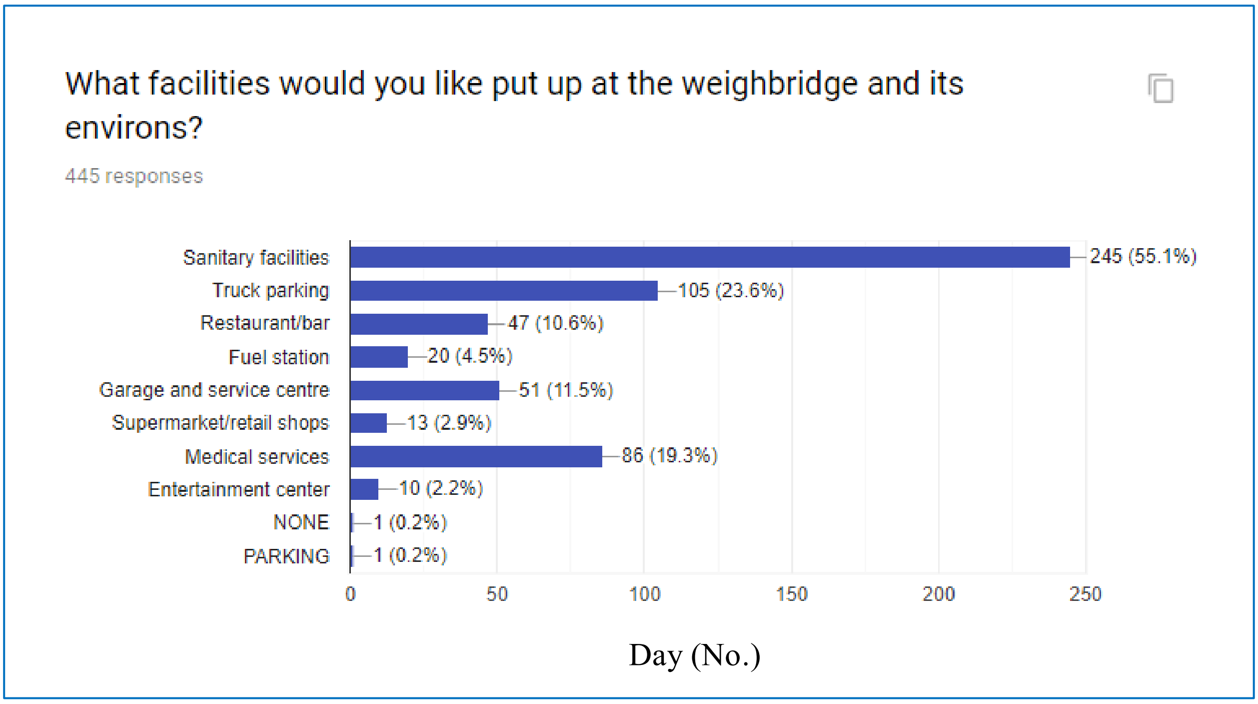

Figure 4. 5 Parking Facilities required by Truck Drivers in Mlolongo

Source: Author, 2017

(m) **Rest Duration:** Five four percent of respondents provided feedback that their employers had not allocated any resting time for them as part of their trips. Additionally, 37 % of respondents indicated their preference to rest at *Mlolongo*, whilst 16% stated the likelihood of their stopping anywhere they deemed was safe along the Northern Corridor, to rest. Only 10% of respondents preferred to stop at the *Machakos* junction and 8% of respondents in Nairobi.

The drivers' responses to the survey demonstrated definite preferences and priorities when it comes to choosing where they will park, neither of which are surprising nor complicated. Drivers prefer parking facilities that provide food, fuel, restrooms, and showers. They also consider safety and security important when they park their trucks. Most survey respondents indicated that they rarely or almost never find available parking at public rest areas. Fewer respondents reported such consistent trouble finding available parking at private truck stops; however, the number one recommendation made by drivers for improving the parking situation was to build more truck stop spaces. Drivers participating in this survey were grateful for the opportunity to share their perspectives. They expressed a willingness to work together with industry and safety stakeholders to improve truck parking along the Northern Corridor.

4.3.2 Truck Volume Data

The truck volume data in this study was obtained from daily weighbridge logs recorded by the High-Speed Weigh in Motion (HSWIM) screening device and stored by Kenya National Highways Authority (KeNHA). The enumerators counted the number of daily traffic volumes passing through from Mombasa to Nairobi and vice versa, from 1st to 7th of October 2018, and made inferences from the data collected. The main purpose was to identify the behaviour of truck drivers in terms of their arrival at the station for service. Data from these logs was validated by the system software for removing outliers. The largest volumes of vehicles (excluding passenger cars) were composed of 2-axle trucks and buses, 6-axle semi-trailers, 3-axle trucks and 5-axle semi-trailers respectively (See Table 4.2)

Table 4. 2 Category of Vehicle Classes

Category of Class EUR13 - EN			
2	***Delivery vehicles, 2 axles***	8	*4 axles semi-trailer*
3	***3 axles trucks***	9	*5 axles semi-trailer*
4	***4 axles trucks***	10	*4-5 axles semi-trailer (1-2 trailer)*
5	***2 axles trucks + trailer***	11	*6 axles semi-trailer*
6	***3 axles trucks + trailer***	12	*2 axles trucks and buses*
7	***3 axles semi-trailer***	13	*7 or more axles, non-classified vehicles*

Source: Author, 2017

For Nairobi Bound traffic, the peak traffic flow volumes were observed in the middle of the week. There were variations in the traffic flow volumes during alternating days, with the lowest traffic flow volumes observed on Sunday. For example, the study recorded 5,763 trucks as the highest volume of vehicles passing through the auxiliary lane (vehicles weighing above 3.5T) for Nairobi bound traffic on the 3rd of October 2018 (See Figure 4.6). From this total, 1,156 trucks were directed into the weigh station to be weighed on the static scale. This is approximately 20% of the total number of trucks on the HSWIM screening device in a day.

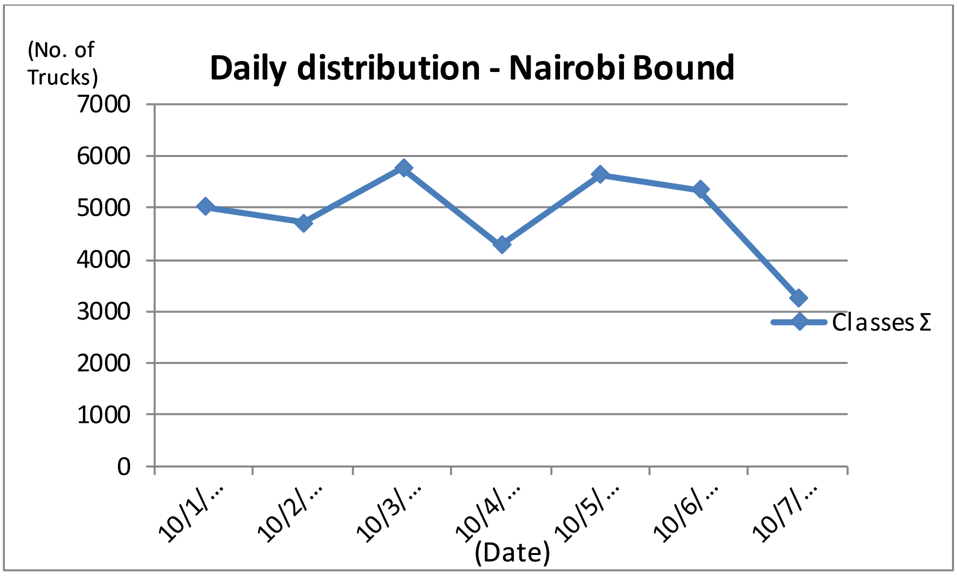

Figure 4. 6 Nairobi Bound Daily Distribution of Traffic

Source: Author, 2018

On Tuesday the 9th of October 2018, the survey recorded 5,380 medium to heavy goods vehicles, which was the highest weekly traffic flow volume. This later peaked to 5,663 vehicles on Friday the 12th of October 2018 (See Figure 4.7)

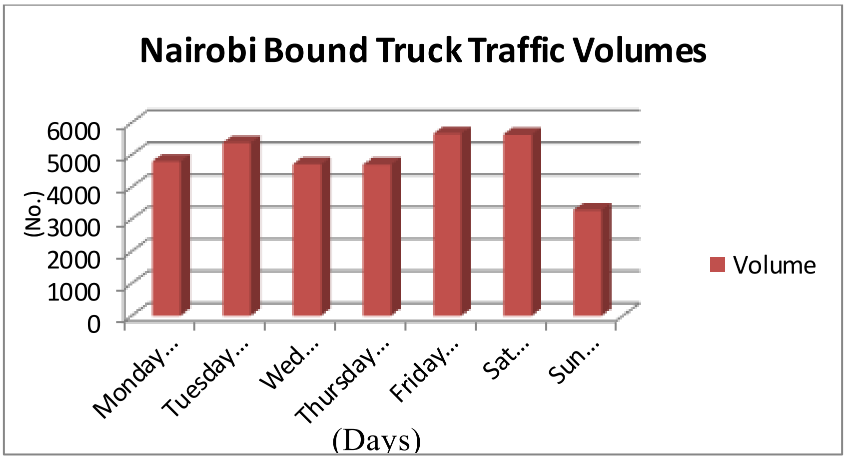

Figure 4. 7 Nairobi Bound Daily Traffic Volumes

Source: Author, 2018

Table 4.3 highlights the vehicular distribution for Nairobi bound traffic, except for Class 1 vehicles, which are excluded from the period 8th-14th October 2018, when data collection was undertaken.

Table 4. 3 Vehicle Classification from 8-14th October 2018

Time	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Volume
Monday 08/10/2018	17	681	17	4	6	0	1	108	0	1386	2527	54	4801
Tuesday 09/10/2018	19	722	15	1	7	0	0	101	0	1771	2693	51	5380
Wed 10/10/2018	13	580	41	1	6	0	1	100	3	1758	2150	58	4711
Thursday 11/11/2018	17	638	35	2	3	0	2	121	3	1395	2424	60	4700
Friday 12/10/2018	11	675	22	3	11	0	0	108	9	1838	2930	56	5663
Sat 13/10/2018	16	621	44	5	14	0	2	103	5	2093	2655	76	5634
Sun 14/10/2018	10	283	8	3	12	0	0	75	1	1680	1155	62	3289
Total Count	103	4200	182	19	59	0	6	716	21	11921	16534	417	34178

Source: KeNHA,2018

In contrast, the traffic flow volumes for the Mombasa bound traffic increased consistently throughout the week and dropped to its lowest peak during the weekend (See Figure 4.8). The 5th of October 2018 recorded the highest traffic flow volume at 6,346 vehicles. However, only a total of 373 trucks were directed into the static scale for confirmatory weighing. Nine cases of overloading by transporters were reported during this week, resulting in the vehicles being grounded at the holding area for more than a day.

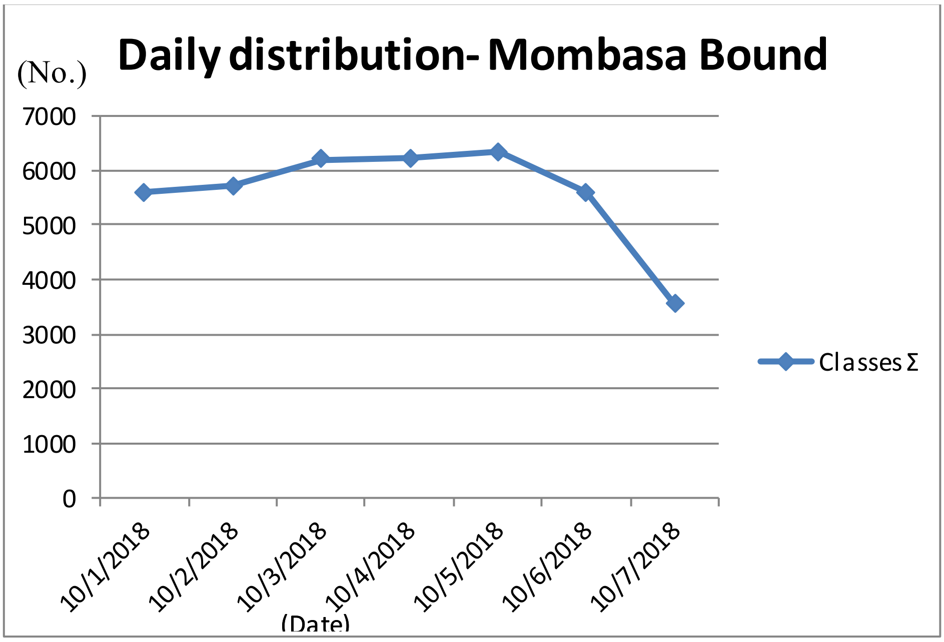

Figure 4. 8 Mombasa Bound Daily Distribution of Traffic

Source: Author, 2018

The daily traffic flow volumes for the Mombasa bound transporters are summarized in Figure 4.9 below:

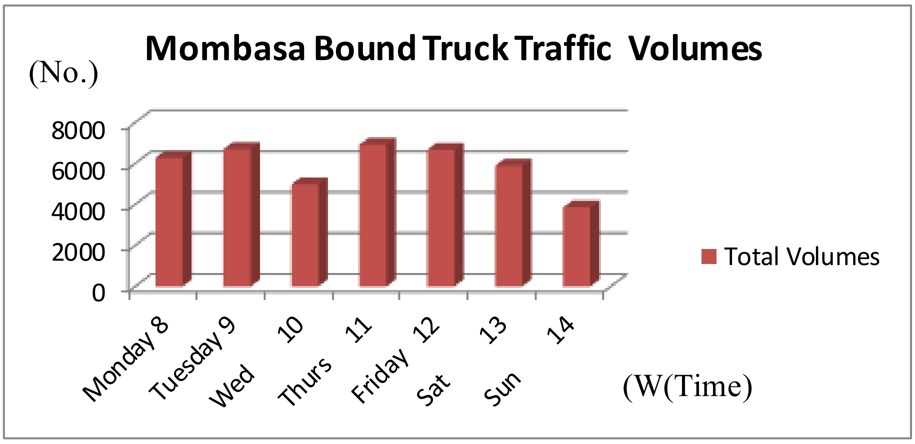

Figure 4. 9 Mombasa Bound Daily Traffic Flow Volumes

Source: Author, 2018

The vehicular distribution for Mombasa bound truck traffic is summarized in Table 4.4 below.

Table 4. 4 Mombasa Bound Truck Traffic Distribution

Time	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Σ
Monday 8/10/2018	28	745	21	7	22	0	9	526	17	1284	2905	344	6279
Tuesday 9/10/2018	29	777	16	7	19	0	7	545	19	1407	3112	373	6710
Wed 10/10/2018	22	504	40	5	25	0	9	450	24	1145	2080	377	4984
Thurs 11/10/2018	30	828	46	13	21	0	13	614	21	1379	3153	390	6915
Friday 12/10/2018	35	728	21	16	15	0	9	520	18	1399	3128	414	6667
Sat 13/10/2018	22	641	45	9	19	0	10	436	15	1246	2621	484	5898
Sun 14/10/2018	14	242	15	5	10	0	5	417	23	1158	1325	398	3863
Totals	180	4465	204	62	131	0	62	3508	137	9018	18324	2780	41316

Source: Author, 2018

4.4 Parking Accumulation Surveys

A count of the number of vehicles parked within Zones A-F and the weighbridge stations (Zones G and H) at regular predetermined intervals, was undertaken. Since the existing parking areas were located along the shoulders of the roads, the parking capacity in each zone could not be defined using innovative survey technologies. Therefore, the distances of each zone were measured manually and developed from the design vehicle WB-62[1] (HCM, 2010) of 20m length and 2.5m width, to estimate the number of trucks that can be accommodated.

4.4.1 Zone A

Zone A has a span of 0.8km from the Old Mombasa Road (see Figure 4.10) and has a capacity of 80 trucks. It provides access to the industrial side of *Mlolongo*, serving manufacturing factories and quarry sites with access to the road. The constriction provided by KeNHA after the upgrade of the weighbridge station serves to restrict vehicles from bypassing the weighbridge and passing through the town and back onto the highway.

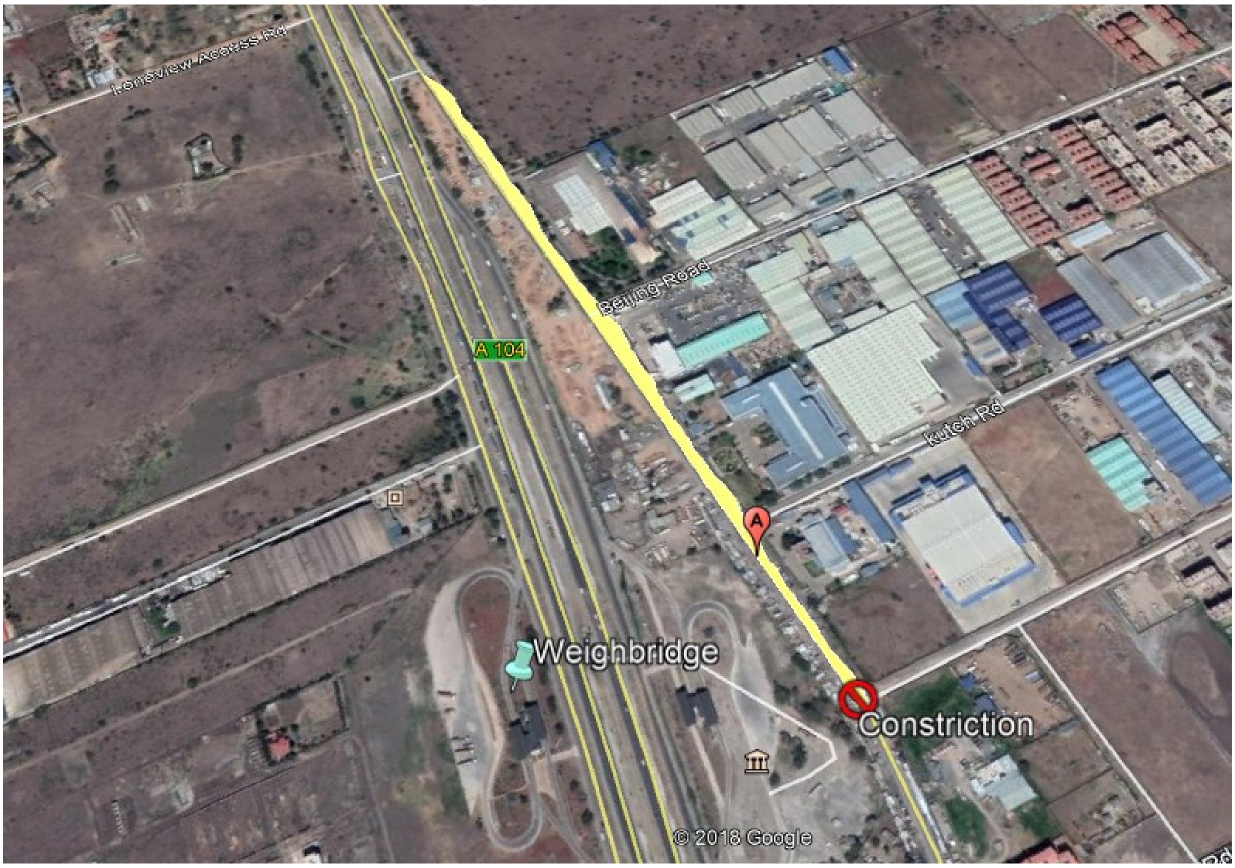

Figure 4.10 Zone A along the Old Mombasa Road

Source: Google Maps, 2018

A total of 275 vehicles were sampled for determining parking durations during the four survey days, with the highest number of observations recorded on Tuesday. The data collected on the daily parking volume established that on average there are 107 vehicles in Zone A. Notably, a

[1] WB-62 (WB-19) is a semitrailer with 62 ft. (18.9m) wheelbase and a radius of 45ft (13.7m)

record 73 vehicles was observed as the highest number of vehicles parked in the mid mornings and afternoons, for short periods of time. This implies that many transporters parked along Zone A are on a short haul, and predominantly consist of tippers, travelling to and from quarries, to include delivery vehicles serving this industrial zone. Figure 4.11 summarizes the parking accumulation curves from the study, whilst Figure 4.12 illustrates the parking durations over the four days of the survey.

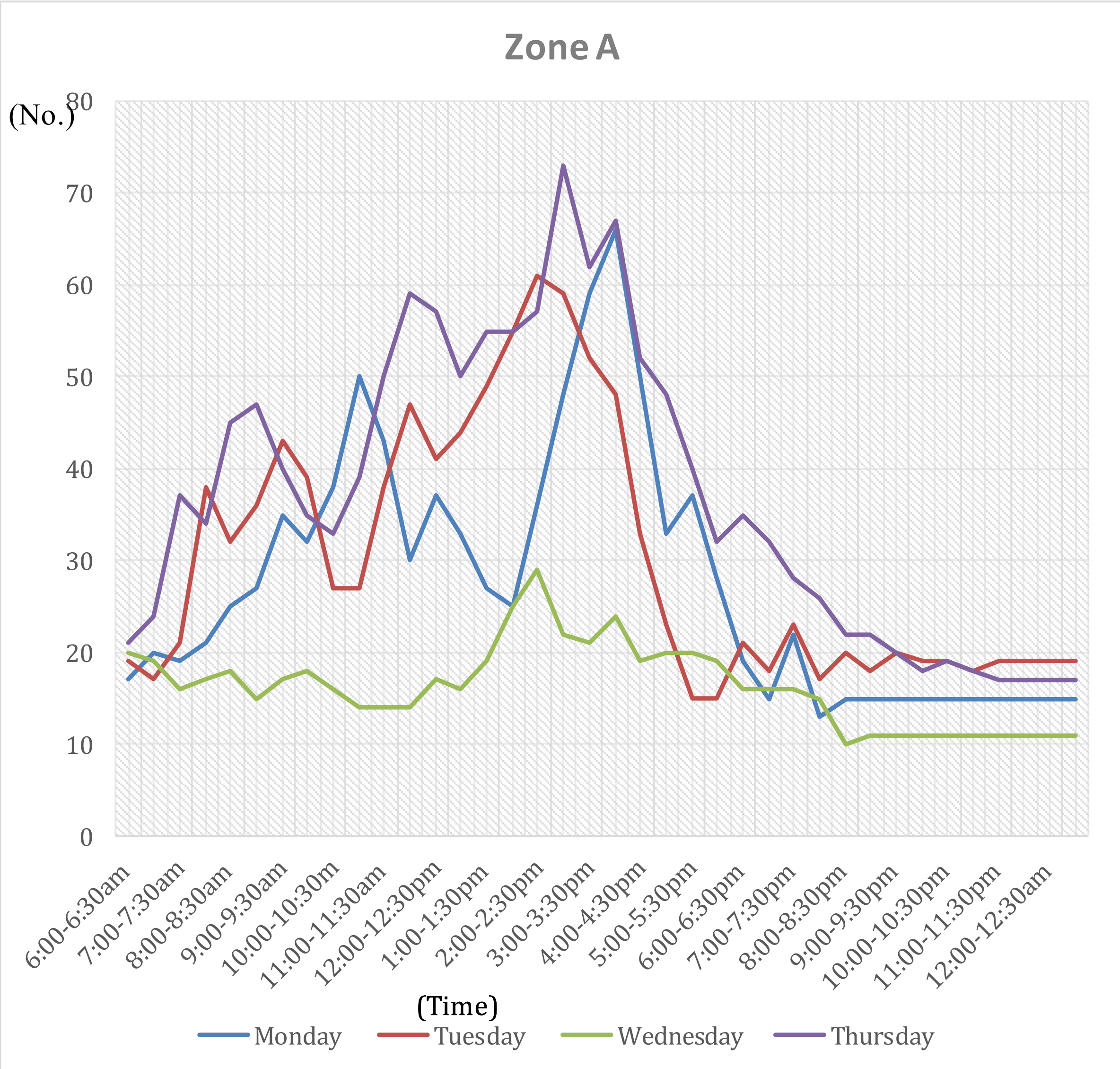

Figure 4.11 Parking durations

Source: Author, 2018

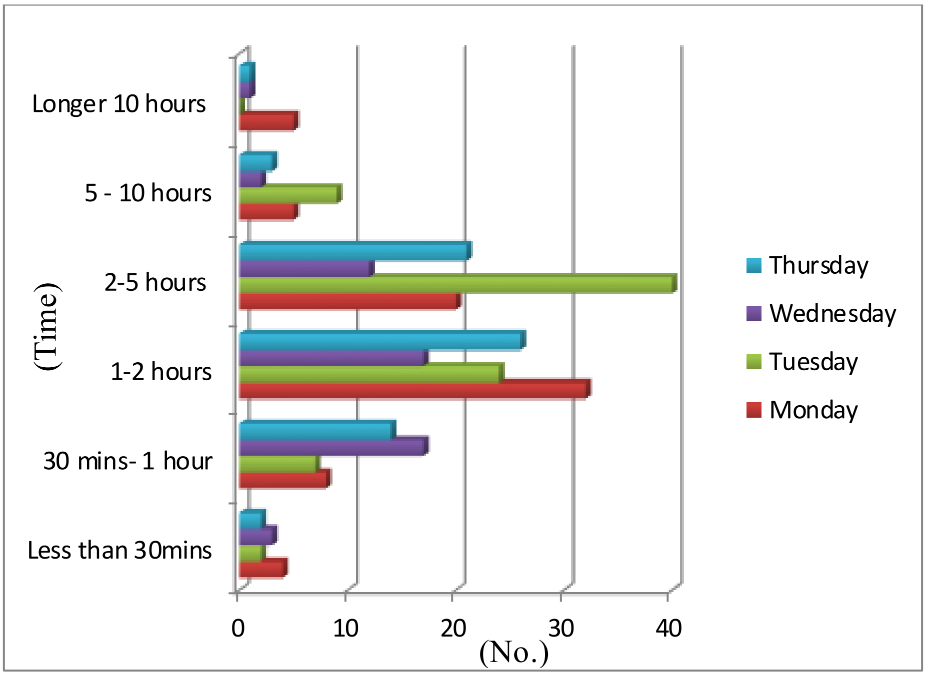

Figure 4. 12 Parking Durations in Zone A from 8th-11th October 2018

Source: Author, 2018

During the peak hours, the number of vehicles parked almost matches the capacity while at low peak, the utilization of parking spaces is almost at 50% of the capacity. There was a significant reduction in the total number of trucks parked on a public holiday, with 46 vehicles recorded, and a peak of 29 vehicles between 2:00pm and 2:30pm respectively. Low parking volumes were observed in the evenings.

The private parking adjacent to the weighbridge is the preferred option for transporters that can find space within Zone A, instead of parking along the shoulders of the road. This facility has 25 parking spaces that are leased for a fee of KShs.100 each (USD 1), during the daytime and KShs. 200 (USD 2) each, if the vehicle is left overnight. The parking fee is paid directly to the private security and no receipt is issued.

Zone A also houses a fuel station, and several garage and repair services, which attract trucks and vehicles to the area. During the time the parking accumulation survey was conducted, an average of 45 vehicles per day went into the garage and repair services. Further, an average of 25 small vehicles per day were parked in Zone A.

4.4.2 Zone B

Zone B begins follows Zone A and extends for 1.1km up to the point at which Old Mombasa Road meets with Mombasa Highway at Mulley's Supermarket. Zone B is a mixed commercial-residential zone, which provides amenities and services including accommodation for the many truck drivers in *Mlolongo* as shown in figure 4.13 below.

Figure 4.13 Zone B in Mlolongo Town along the Old Mombasa Road

Source: Author, 2018

Zone B has a truck parking capacity of 110 slots, with consideration of the design vehicle WB-67 of 20m length. This includes the fact that the trucks can be parked on both sides of the road {(1100/20) * 2} =110 slots. The study also identified on street parking for some of the businesses along Zone B; an estimated 50 parking spaces that were not necessarily allocated for large trucks. This implies that the total approximate capacity of parking Zone B is 160 spaces.

Parking space usage at Zone B includes other vehicles besides trucks, and averages about 100 vehicles. Due to the public holiday on Wednesday, the researchers noted an increased usage, recording 171 other types of vehicles parked in the zone. Without adequate pedestrian walkways, pedestrians are forced to walk along the road, which is also encroached by the road-side vendors (See Plate 4.1 below)

Plate 4.1 Pedestrians and Road-side Vendors along Zone B

Source: Katie Mzungu in Kenya, 2013

The researchers collected data on the number of trucks parked by time of day, the number of trucks parked in designated spaces, and the length of time each truck remained parked in Zone B. The accumulation and duration data were collected between the 8th-11th October 2018 (See Figure 4.14), and the findings provided as follows:

- On Monday, 8th October 2018, the truck parking volume was recorded at 94 vehicles, with the zone experiencing a peak of 45 trucks in the early morning, between 6:00 am and 6:30 am.
- On Tuesday 9th October 2018, after 19-hour counts, the truck parking volume was established as 117 vehicles, with a peak of 60 trucks between 8:30pm and 9:00pm. Markedly, the truck parking volume increased significantly from 7:00pm, as most businesses close for the day. This implies that service or delivery vehicles park near their businesses overnight and proceed to make trips during the day.
- The data collected on Wednesday 10th October 2018, indicated that the usage of parking spaces was low, with a total volume of 98 vehicles and a peak of 55 vehicles between 10:00pm and 10:30pm.
- On Thursday 11th October 2018, the number of trucks parked in Zone B was 104, with a maximum number of 50 trucks between 10:00pm and 10:30pm.

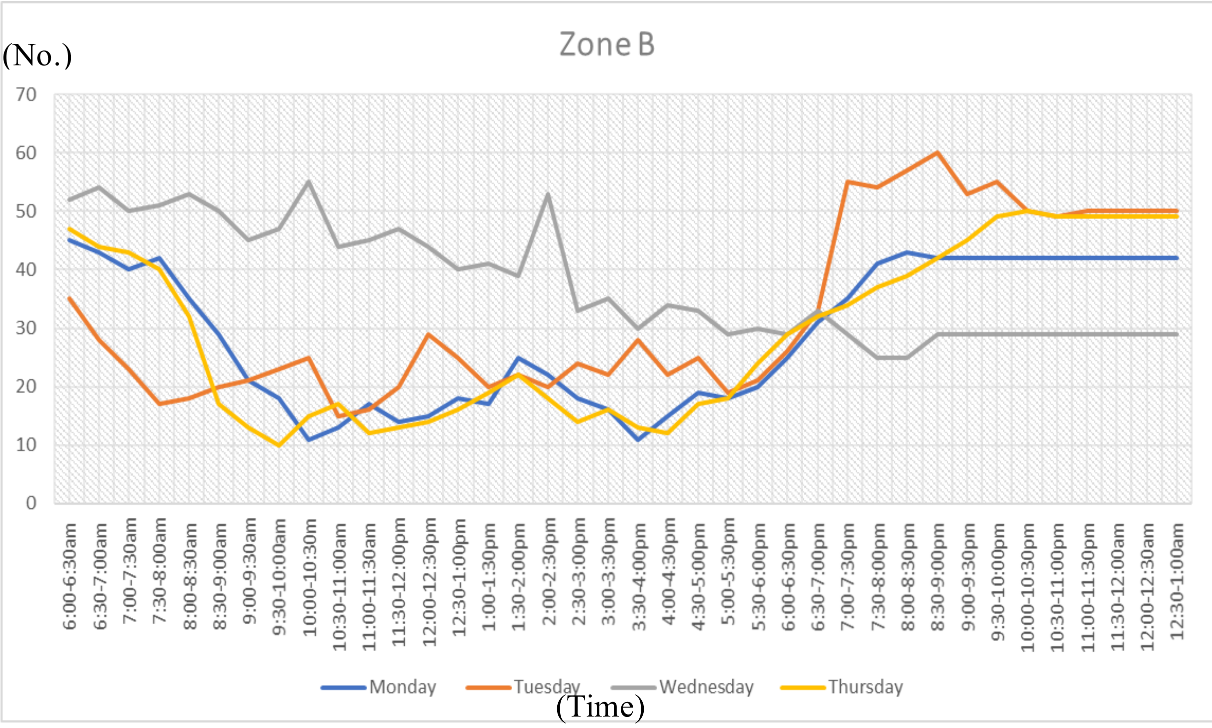

Figure 4.14 Parking Accumulation for Zone B

Source: Author, 2018

Figure 4.14 above illustrates the parking accumulation and duration data in Zone B was highest on Tuesday 9th and Thursday 11th. Most vehicles were parked for 5-10 hours, or later stayed overnight. Notably, vehicles parked during the day did so for short durations.

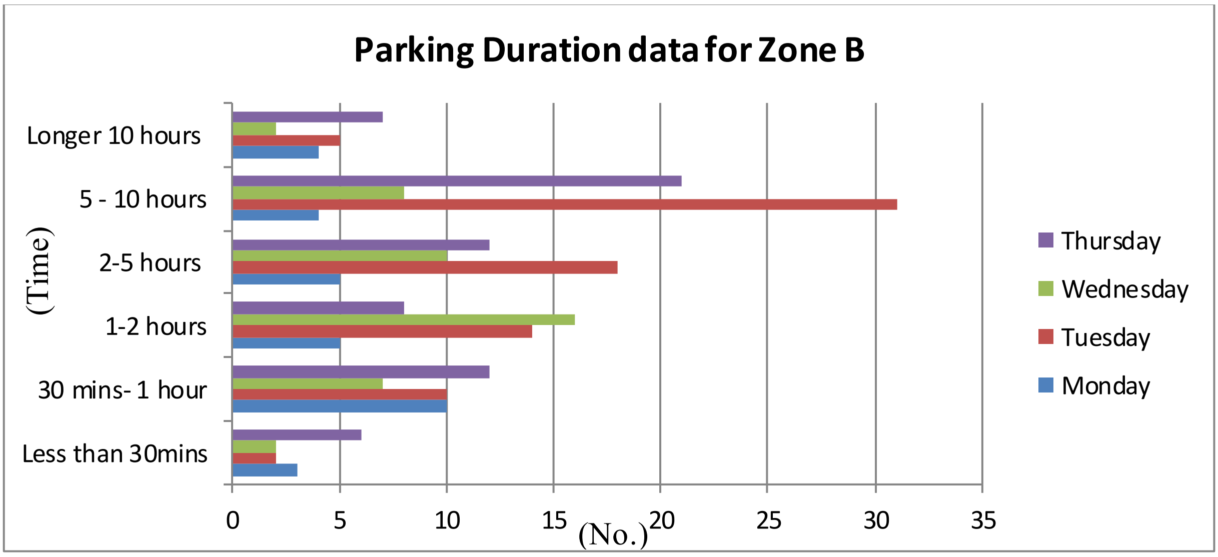

Figure 4.15 Parking Durations for the Survey Period in Zone B

Source: Author, 2018

4.4.3 Zone C

Zone C covers the largest individual area of the study, spanning 1.5 kilometers from the Mombasa bound weighbridge station to Mulley's supermarket, and further until the *Mlolongo* footbridge (See Figure 4:16 below).

Figure 4. 16 Aerial image of Zone C

Source: Google Earth, 2018

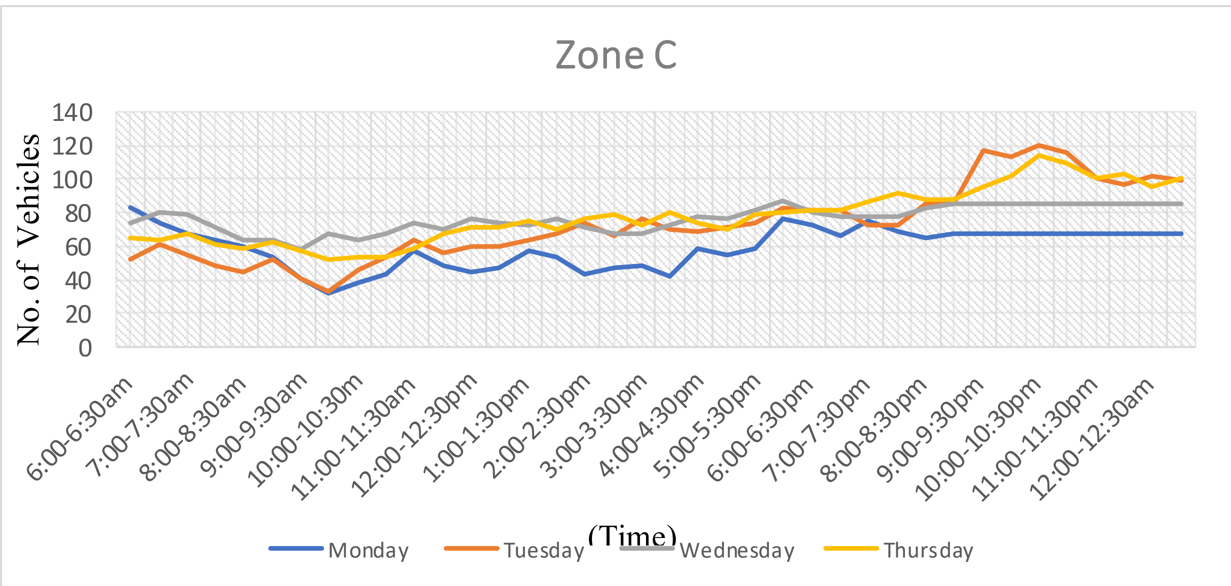

Figure 4. 17 Parking and Accumulation for Zone C

Source: Author, 2018

Parking duration data was collected from 446 vehicles over a period of 4 days. Preliminary information received indicated that most truck vehicles were parked for short periods between 30 minutes to 2 hours during the day (See Figure 4.18), allowing the drivers to access roadside services and amenities. These high volumes gradually decreased during the day, due to patrols undertaken by the Inspectorate. Information received from truck owners/managers indicated a preference for drivers to stay overnight in *Mlolongo*, as the area was well lit, with plenty of activities taking place. Findings revealed a 41% increase in the number of trucks parked between 8:00 – 10:00pm in Zone C from Monday to Thursday (See Figure 4.17). Most drivers who stayed the night were parked for 2-5 hours, thereafter they continued with their trips.

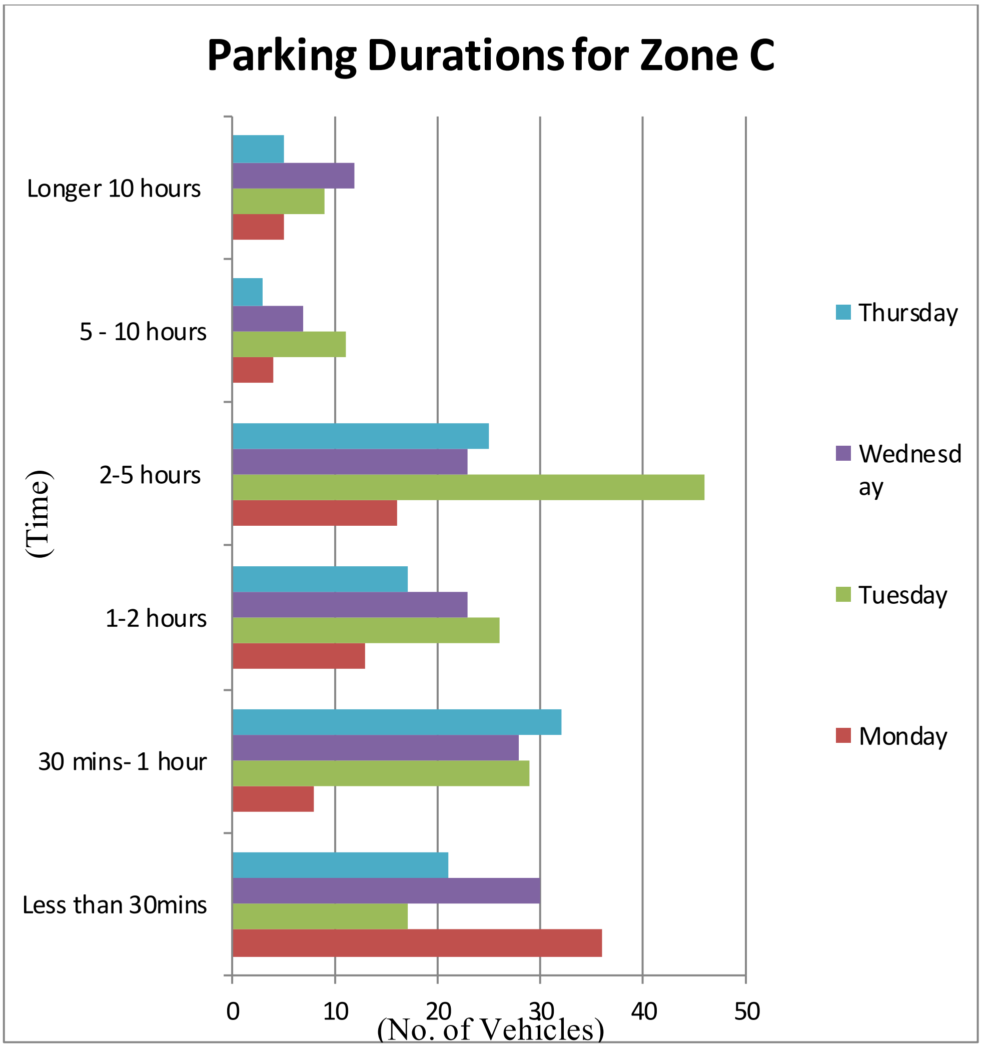

Figure 4. 18 Parking Duration graph for Zone C

Source: Author, 2018

4.4.4 Zone D

Spanning approximately 0.5 Km long, Zone D extends from the Nairobi bound weighbridge to the entrance of Olympia Petrol Station, and back along the footbridge (See Figure 4.19). This zone has a capacity of 50 trucks along the roadway, an additional 30 parking spaces allocated for commercial businesses, bring the total parking spaces to 80. Findings revealed a low truck parking usage in this zone. This was likely due to the heavy penalties imposed on truck drivers, who parked within 2 KM of the weighbridge.

Figure 4. 19 Aerial photograph of Zone D

Source: Google Earth, 2018

The researchers collected data on the number of trucks parked by during the day, the number of trucks parked in designated spaces, and the parking duration in Zone D. The study also observed several buses parked in this zone, from different Sacco's. The accumulation and duration data were collected between the 8th-11th October 2018 (See Figure 4.20), and the findings provided as follows:

- On Monday 8th and Tuesday 9th October 2018, there were a total of 24 trucks parked in Zone D, in the mid-morning hours, with a total volume of 75 trucks throughout both days.
- On Wednesday, the researchers noted a higher parking load, recording a peak of 44 trucks between 7:00- 7:30pm, with a total volume of 85 trucks in throughout the day.

- On Thursday, there was a high parking load between 6:00am- 6:30am, which later decreased after a couple of hours to mirror the parking volumes previously recorded on Monday and Tuesday, respectively.

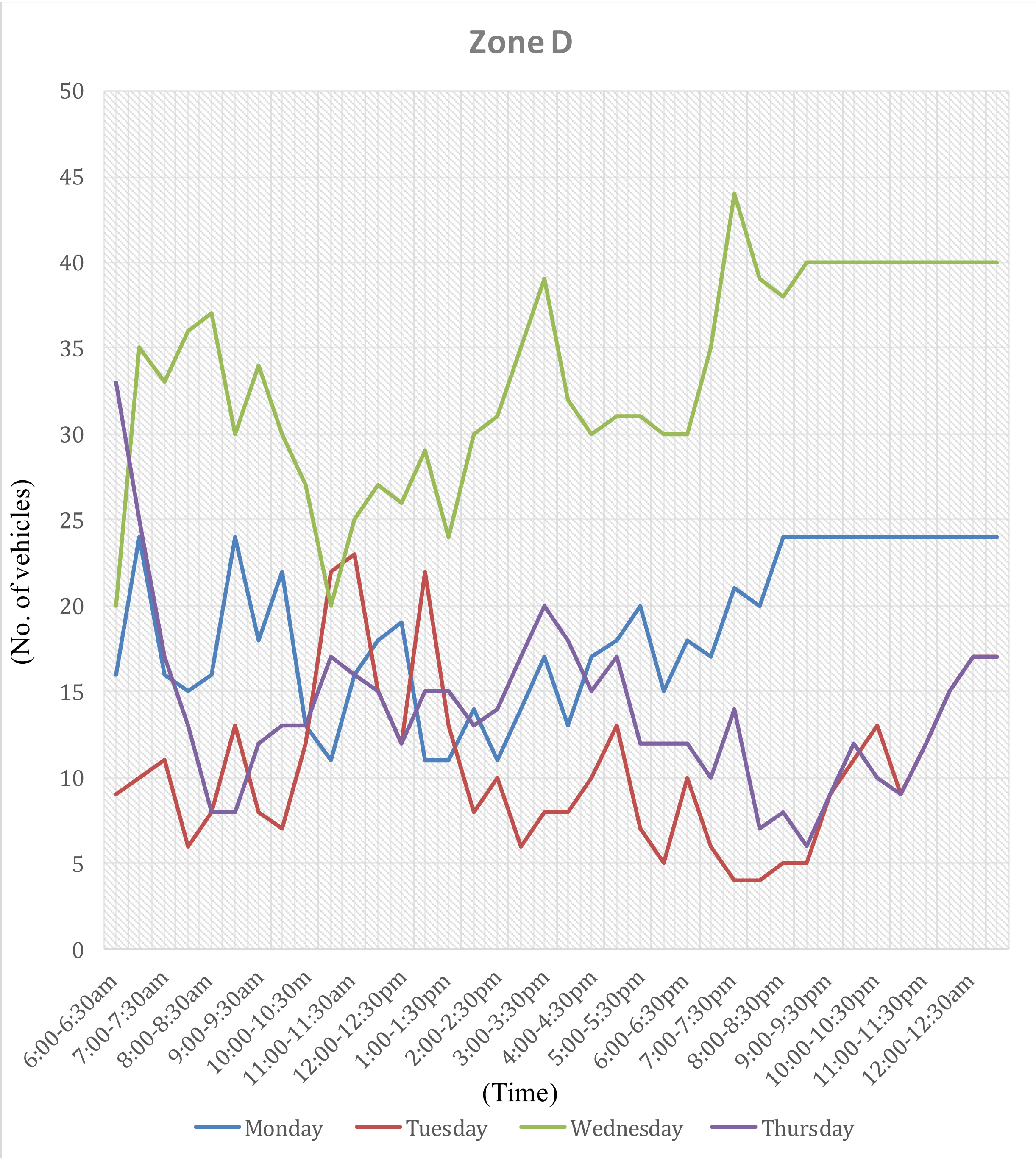

Figure 4. 20 Accumulation graphs for Zone D

Source: Author, 2018

The parking duration data revealed that truck vehicles were parked in Zone D between 2-5 hours (See Figure 4.21) This is due to inaccessible parking, prior to the truck's arrival at the weighbridge service. Overall, the truck parking volumes in Zone D were minimal, with little variation through the day.

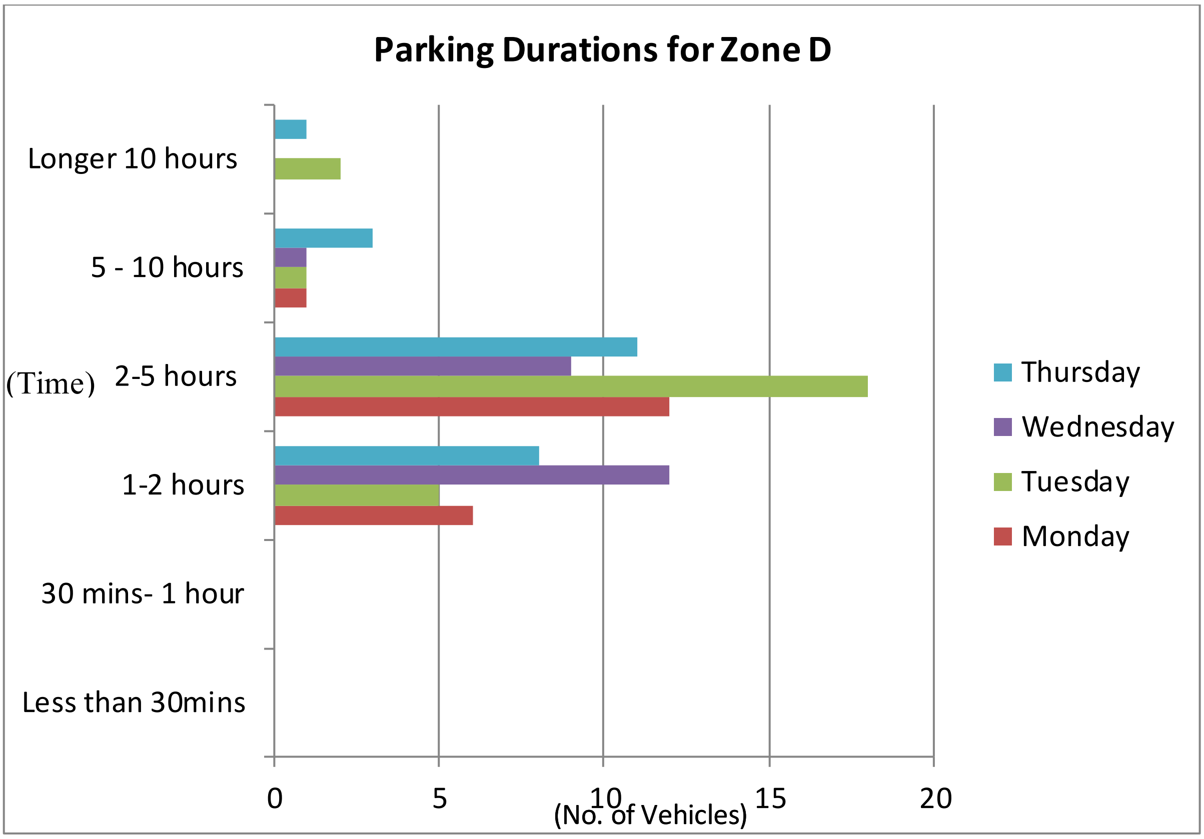

Figure 4. 21 Parking Duration Data for Zone D

Source: Author, 2018

On average, 15 buses were parked in Zone D, every hour between 6:00am -11:00am, to include overnight near the petrol station. In particular, Figure 4.22 illustrates the parking accumulation of buses within the zone on Thursday, 11th 2018. This implies that the planning for a parking facility should consider buses.

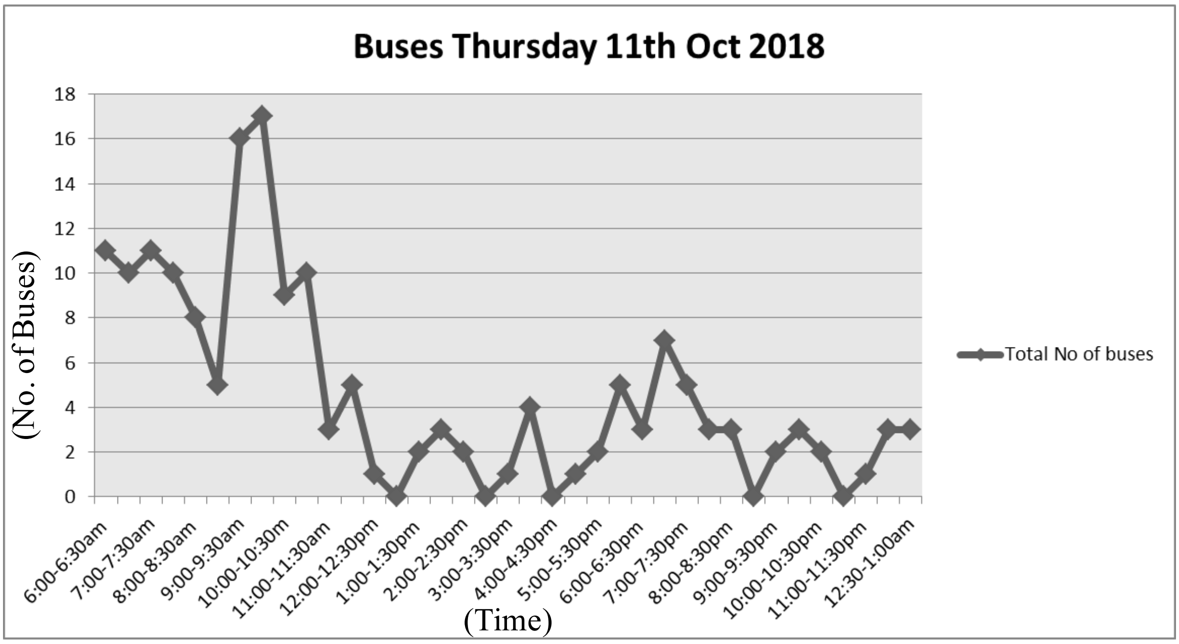

Figure 4. 17 Bus Accumulation Graph for Thursday 11th October 2018

Source: Author, 2018

4.4.5 Zone E

Zone E stretches from the Nairobi bound weighbridge downstream, thereby serving trucks that park after service at the weighbridge. It extends for 0.7 KM from the weighbridge exit, to where the service lane joins the highway. Whereas Zone E (See figure 4.22) has a parking capacity of 70 trucks, the truck drivers park along the shoulders of the highway in this zone, and there is no designated parking area.

Figure 4. 22 Aerial image of Zone E

Source: Author, 2018

Data was collected on the number of trucks parked during the day, for the number of trucks parked in designated spaces, and the length of time each truck remained parked in Zone E. Findings revealed a low truck parking usage, and this was attributed to the close proximity of the weighbridge station, along the Nairobi bound station. The accumulation and duration data were collected between the 8th-11th October 2018 (See Figure 4.23), and the findings provided as follows:

A maximum of 72 trucks were parked in this zone on Tuesday 9th October 2018, with a peak value of 39 vehicles parked between 11:30pm and midnight. On Wednesday 10th October, the parking volumes were low, with a total volume of only 48 trucks throughout the day.

This zone was popular amongst drivers transporting hazardous materials, with an average of 13 tankers parking here daily. Respondents stated that despite parking being illegal along the weighbridge, the truck drivers were drawn by the level of security in this area. This indicates that security is a major consideration in the choice of parking area.

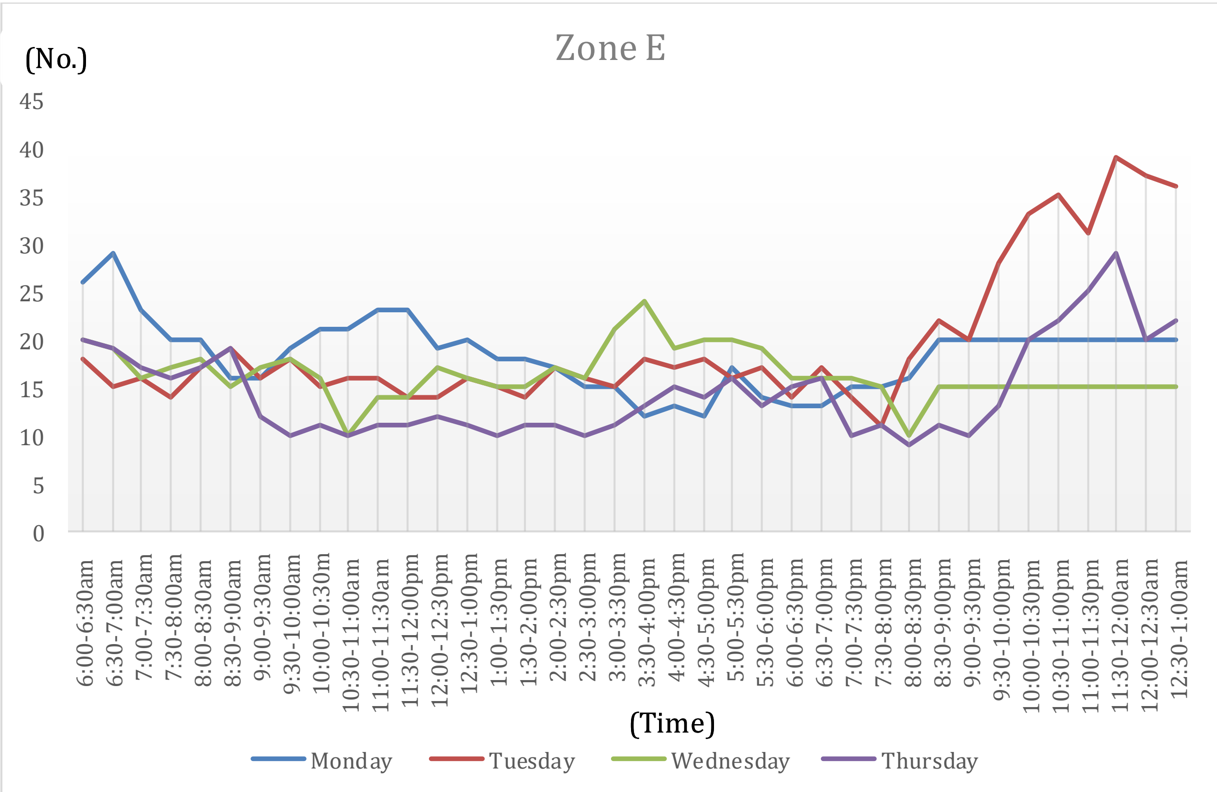

Figure 4. 23 Accumulation Graphs for Zone E

Source: Author, 2018

Figure 4.24 below illustrates that the parking duration data in Zone E occurred mostly over a duration of 2-5 hours, or 5-10 hours. This was largely due to the fact that many drivers either parked their vehicles overnight or were making a quick stop within the zone.

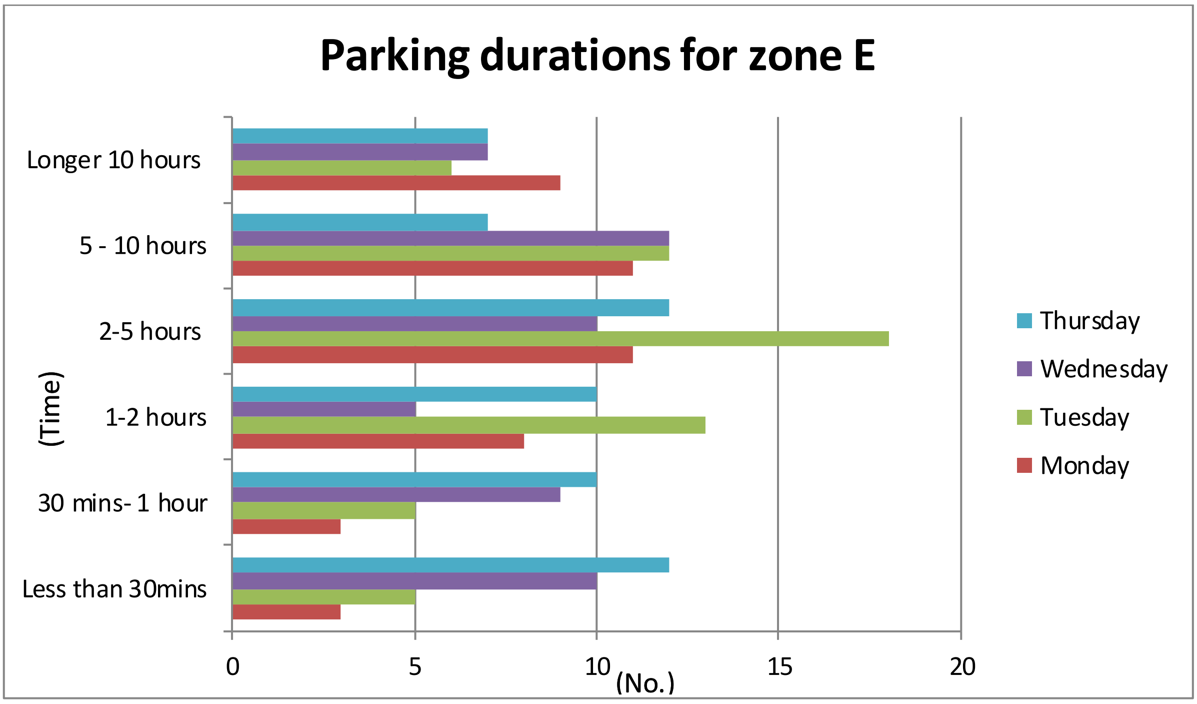

Figure 4. 24 Parking Duration Graph for Zone E

Source: Author, 2018

4.4.6 Zone F

Many trucks, which use the Nairobi bound weighbridge station, stop at the upstream side, demarcated as Zone F (See Figure 4.25). The zone has several garages and service points, businesses, and private parking areas. It is 1.2KM in length, and extends from the Mlolongo footbridge to Olympia Petrol station, which is the boundary between Zone D and F. The zone is estimated to have a capacity of 210 trucks as calculated below:

Along the highway -	(1200/20) * 2	= 120 spaces
Garages and private parking-		= 30 spaces
Service lane	(500/20)	= 25 spaces
		= 155 spaces

Figure 4. 25 Aerial image of Zone F

Source: Google Maps, 2018

The collected data on the number of trucks parked during the day, for the number of trucks parked in designated spaces, and the length of time each truck remained parked in Zone F. The accumulation and duration data were collected between the 8th-11th October 2018 (See Figure 4.26), and the findings provided as follows:

- An average of 144 trucks parked throughout the day, with a peak value of 76 trucks occurring between 8:00pm and 11:00pm.
- On Wednesday 10th 2018, there were low parking usage volumes observed throughout the day, with peak volumes of 54 trucks evidenced from 8:30pm to 9:00pm, and a total of 92 vehicles throughout the day.
- An average of 4 tankers per day containing hazardous materials such as Liquefied petroleum gas (LPG) and petroleum parked in Zone F, to include 15 trucks that were parked in the garage.

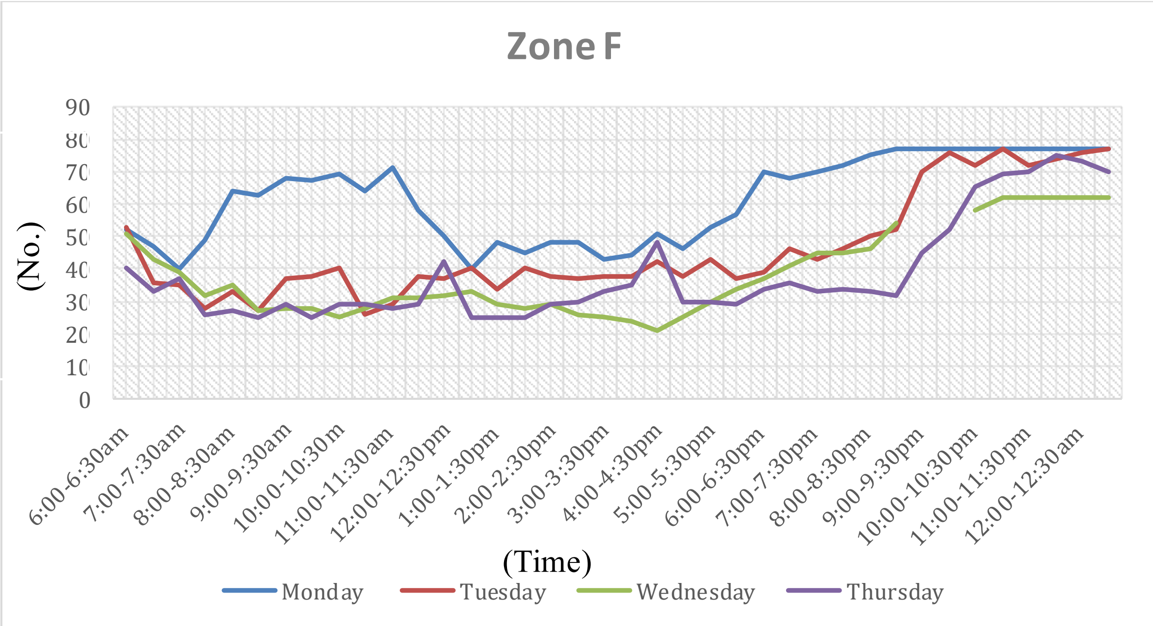

Figure 4. 26 Parking Accumulation graph for Zone F

Source: Author, 2018

There were two small private parking areas in this zone, with 15 parking spaces each. These spaces doubled up as garages, car wash and service centers. Overnight parking attracted a charge of KShs. 500 and day parking was at KShs. 200. Figure 4.27 illustrates the parking duration data in Zone F, whereby trucks are parked for 2-5 hours, with highest parking numbers recorded at night. Due to the numerous services and amenities in this zone, there is a high park volume usage.

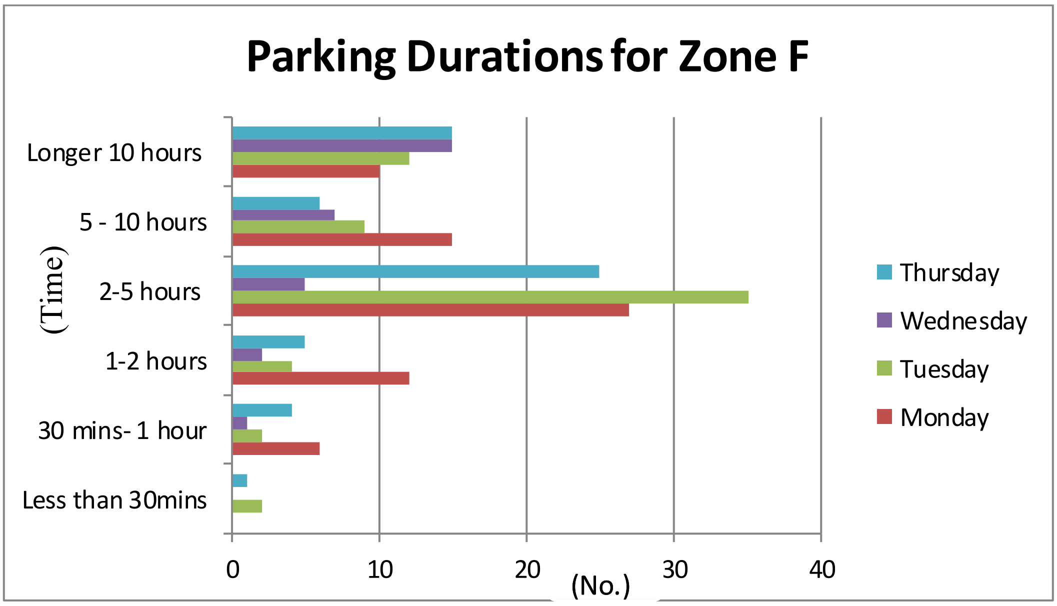

Figure 4. 27 Parking Duration graph for Zone F

Source: Author, 2018

4.4.7 Summaries

The parking data collected from Zones A to F (See Figure 4.28) on the four stipulated days, was aggregated and it was found that the truck parking requirements at *Mlolongo* on average, per day is 675 vehicles.

Figure 4. 28 Average daily Truck Parking Volumes, per Zone

Source: Google Earth, 2018

The survey revealed that most zones had no designated truck parking capacity, especially the zones with high truck volumes, such as Zone C and Zone F along the highway (See Table 4.4 below). In addition, Zone A and B, along the old Mombasa Road also recorded high truck parking volume usage.

Table 4. 5 **Truck Parking Volumes per zone**

	MOMBASA BOUND			NAIROBI BOUND		
Day	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Monday	138	94	171	59	47	142
Tuesday	108	117	186	75	72	154
Wednesday	46	48	82	85	48	92
Thursday	108	104	167	59	58	134

Source: Author, 2018

Findings revealed that most parking facilities were at capacity during night hours and some during daytime hours as well, such as Zones A, C and F respectively (See Table 4.6).

Table 4. 6 **Maximum Truck Parking Volumes per zone**

	MOMBASA BOUND			NAIROBI BOUND		
Day	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Monday	66	45	83	24	29	77
Tuesday	61	60	120	23	39	77
Wednesday	29	55	87	44	24	54
Thursday	73	50	114	33	29	75

Source: Author, 2018

The design volumes were calculated as 253 vehicles per hour for the Mombasa bound side (Zones A, B and C), and 160 vehicles per hour for the trucks that were Nairobi bound (Zones D, E and F). These values were obtained by picking the maximum values per hour from each zone. Overall, Zone F had the highest parking demand along the Nairobi bound side of the highway (See Table 4.7).

Table 4. 7 Truck Parking Volumes per zone/hour

	MOMBASA BOUND			NAIROBI BOUND		
Day	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Monday	9	6	11	4	3	9
Tuesday	6	6	10	4	4	8
Wednesday	3	3	5	6	3	6
Thursday	6	5	9	3	3	7

Source: Author, 2018

In terms of the parking utilization of each zone, the maximum number of vehicles counted during the survey was compared with the capacity data (See Figure 4.29).

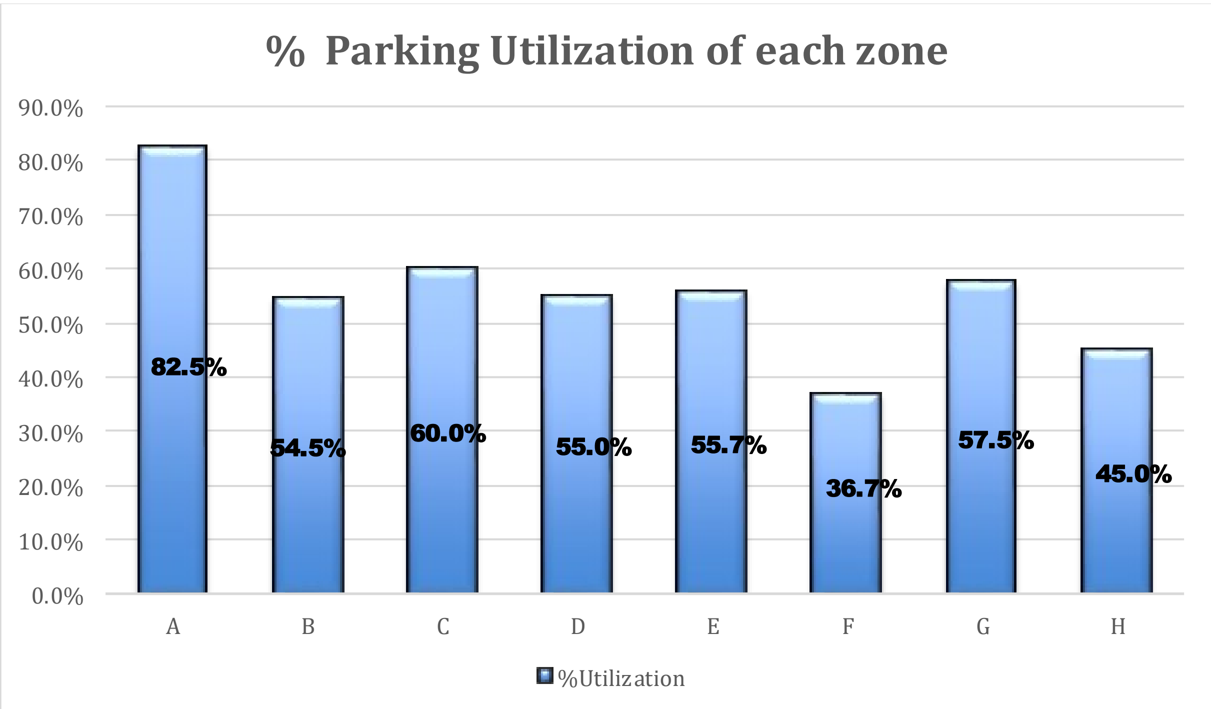

Figure 4. 29 Parking Utilization of Each Zone expressed as a Percentage

Source: Author, 2018

4.4.8 Level of Significance.

Assuming a 95% level of confidence.

Table 4. 8 Parking Demand Data

	MOMBASA BOUND			NAIROBI BOUND		
Day	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Monday	138	94	171	59	47	142
Tuesday	108	117	186	75	72	154
Wednesday	46	48	82	85	48	92
Thursday	108	104	167	59	58	134

Source: Author, 2018

From the parking demand data as shown in Table 4.8, it is evident that Wednesday had the least demand and Tuesday the highest, using the paired t- test for the two measurements, it is hypothesized that there is no significant statistical difference between the means of the two counts as follows:

Null hypothesis assuming a 95% confidence level then the t value is assumed to be 0.05.

Calculating the t- test statistic then the following Table 4.9 is generated.

Table 4. 9 t- test Statistics

Zone	Min	Max	Mean	Min-Max	$(Min\text{-}Max)^2$
A	46	108	77	-62	3,844
B	48	117	84	-59	3,481
C	82	186	134	-104	10,816
D	85	75	80	10	100
E	48	72	60	-24	576
F	92	154	123	62	3,844
Totals				-155	22,661

Source: Author, 2018

To validate this data, refer to equation on t = t-statistic from the student's t-distribution for (n-1) degrees of freedom, and is based on a specified confidence level from equation 4.3 below.

Therefore, applying equation 4.3.

$$t = \frac{\frac{sum(\,min - \max)}{No.of\ zones}}{\sqrt{\frac{sum(min - \ \max\ ))^2 - \frac{sum(min-))^2}{No.of\ zones}}{(No.of\ zones - 1) * No.of\ zones}}}$$

Where;

No. of zones = 8

Sum of min – max = -155

Then;

$$t = \frac{-155/8}{\sqrt{\frac{(-155)^2 - 22661/8}{(8-1)(8)}}}$$

t = 0.051

The t-test statistics results of the null hypothesis hold true. Therefore, the relationship between the maximum and minimum counts are statistically significant. This means that the data is a reliable basis for modelling the parking requirements at the weighbridge location.

CHAPTER FIVE: DATA COLLECTION AND ANALYSIS

5.1 Determination of the Parking Requirements

This chapter presents the application of a quantitative model for truck parking utilization at the *Athi River* Weighbridge. It includes a detailed description of all the methods, as well as a discussion of the results, and policy implications of the final model.

5.1.1 Calculation of the Demand Using Three Models

The step-by-step linear multiple regression model applied in this thesis, utilizes data obtained from the parking accumulation counts, volume counts, parking duration assessments and qualitative data from the questionnaire in order to establish peak hour parking demand in each zone. This zonal data is then aggregated to obtain Nairobi bound and Mombasa bound parking requirements as well as the total peak hour parking demand of Mlolongo weighbridge study area (See Table 5.1).

Table 5. 1 Data for Model Calibration

Zone	Segment description	Segment Length (KM)	Parking capacity
A	Spans from the Old Mombasa Road branch off to the constriction	0.8	80
B	Begins at the constriction separating it from Zone A, extends up to the meeting point of the Old Mombasa Road with the existing Mombasa Highway at Mulley's Supermarket, a mixed commercial-residential zone.	1.1	110
C	Spans from the Mombasa bound weighbridge station to Mulley's Supermarket and further to Mlolongo footbridge. A business hub and busiest parking zone.	1.5	180
D	Extends from the Nairobi bound weighbridge station to the entrance of Olympia Petrol Station	0.5	80
E	Extends off the Nairobi bound weighbridge to the end of the service lane	0.7	70
F	Extends from the Mlolongo footbridge to Olympia Petrol Station which marks the boundary between it and Zone D. Active parking zone	1.2	155

Source: Author, 2018

For the model calibration, the independent variables were identified as Traffic engineering measures such as the Annual Average Daily Traffic (AADT), Hours of Service regulations, variables from driver travel patterns and preferences. The peak demand was observed in the overnight hours between 10:00pm to 6:00am, and estimates on the capacity of each parking zone indicated as shown in Table 5.1. This also included the identification of the Long Haul Peak parking factor (PPF_{LH}) and the Short Haul to Long Haul ratio (P_{SH}/P_{LH}).

The first step involved running the model with a fixed P_{SH}/P_{LH} ratio obtained from the origin destination data, obtained from the truck driver's feedback. The data showed 63% of drivers made long haul trips, and 37% made short haul trips along the highway segment. The ratio is obtained as .37/.63. However, in Zone A the percentage of short haul trips made amounted to 88%, making the ration in this zone .12/.88. The average truck speed in Zones A and B was taken as 35 and 50 kilometers per hour respectively, along the highway segment. An illustration of the excel model inputs are demonstrated below:

Key: ***Italics*** **- Model inputs** **Model Parameters**

For Zone A

Highway Segment Length	*500* Kilometers
Annual Average Daily Traffic	*75,503* vehicles per day
Seasonal Peaking factor	1.15
Percent Trucks	*0.09*
Daily truck Traffic volume	6,643 trucks per day
Percent Short Haul trucks	*0.88 (from field calibration)*
Percent Long Haul trucks	*0.12 (from field calibration*)
Short Haul truck volume	5,846 short haul trucks per day
Long Haul truck volume	797 long haul trucks per day
Average truck speed	*35* kilometers per hour
Travel time in Zone A	14.29 hours per truck
Short Haul Truck-Hours of Travel	409.21 truck-hours per day on the segment

Long Haul Truck Hours of Travel	55.80 truck-hours per day on the segment
Max Hours of Driving per week	77 (from HOS regulations)
Avg. Hrs. of rest per week	30 (derived from survey inputs)
Avg Hrs. spent in Mlolongo per week	18 (derived from survey inputs)
Ratio of driving time to parked time	0.83

The conversion from daily truck-hours of parking to truck-hours per hour can be determined by the peak-hour parking factor (PPF). The units of the peak parking demand (PHP) then become trucks or spaces. Default values for short-haul peak parking factors (PPF_{SH}) have been set at 0.02 for other segments and 0.04 for Zone A. Using these values and the truck hours of parking, the peak-hour short-haul and long-haul parking demand, PHP_{SH} and PHP_{LH}, respectively, has been calculated as follows:

Short Haul Truck Hours Parking Demand	341.01 truck-hours per day
Long Haul truck hours of Parking Demand	46.50 truck- hours per day
Short Haul Peak Parking Factor peak hour (professional judgement)	0.04 proportion of the SH parking demand in the
Long Haul Peak Parking Factor peak hour (model calibration)	0.03 proportion of the LH parking demand in the
Short Haul Peak hour parking demand	14 trucks
Long Haul Peak Hour Parking demand	1 truck

Total peak hour parking demand for Zone A- 15 spaces

For Zone F:

Highway Segment Length	*500* Kilometers
Annual Average Daily Traffic	*75,503* vehicles per day
Seasonal Peaking factor	1.15

Percent Trucks	*0.09*
Daily truck Traffic volume	6,643 trucks per day
Percent Short Haul trucks	*0.37 (from field calibration)*
Percent Long Haul trucks	*0.63 (from field calibration*)
Short Haul truck volume	2,458 short haul trucks per day
Long Haul truck volume	4,185 long haul trucks per day
Average truck speed	*50* kilometers per hour
Travel time	10 hours per truck
Short Haul Truck-Hours of Travel	245.79 truck-hours per day on the segment
Long Haul Truck Hours of Travel	418.51 truck-hours per day on the segment
Max. Hours of Driving per week	77 (from HOS regulations)
Avg. Hrs. of rest per week	30 (derived from survey inputs)
Avg. Hrs. spent in Mlolongo per week	*18* (derived from survey inputs)
Ratio of driving time to parked time	0.83
Short Haul Truck Hours Parking Demand	204.83 truck-hours per day
Long Haul truck hours of Parking Demand	348.76 truck- hours per day
Short Haul Peak Parking Factor	0.01 proportion of the SH parking demand in the peak hour
Long Haul Peak Parking Factor	0.05 proportion of the LH parking demand in the peak hour
Short Haul Peak hour parking demand	2 trucks
Long Haul Peak Hour Parking demand	16 trucks

Total peak hour parking demand for Zone A - 18 spaces

Figure 5.1 provides a summary of the findings from the initial model calibration, with further details.

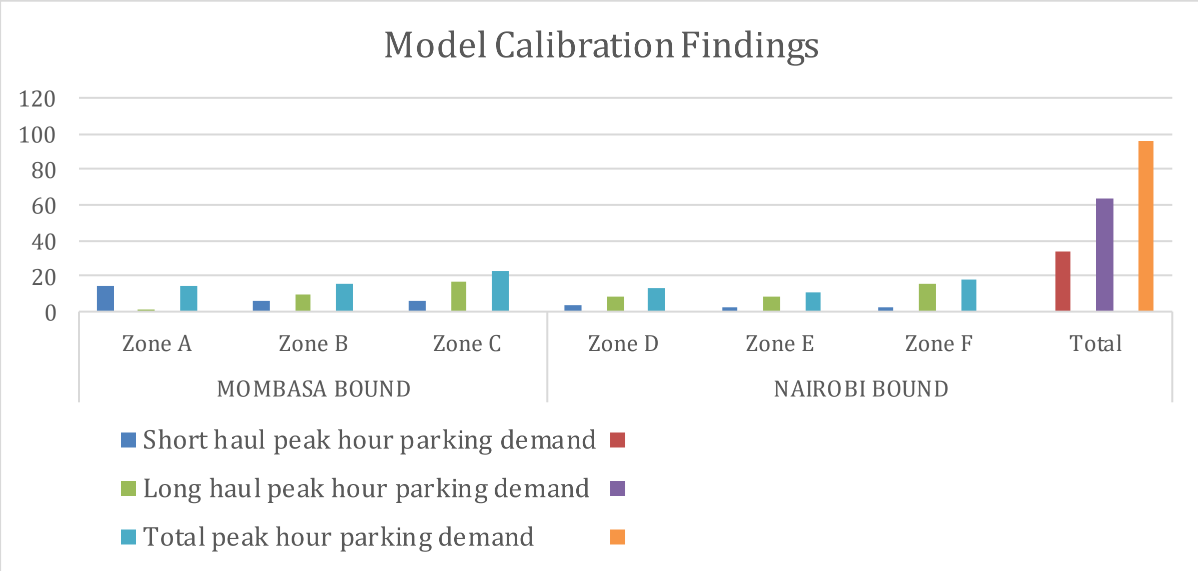

Figure 5. 1 Model Calibration Findings

Source: Author, 2018

Model calibration of the study area through the step-by-step linear regression model yields a total peak hour parking demand of 96 truck parking spaces (See Figure 5.2).

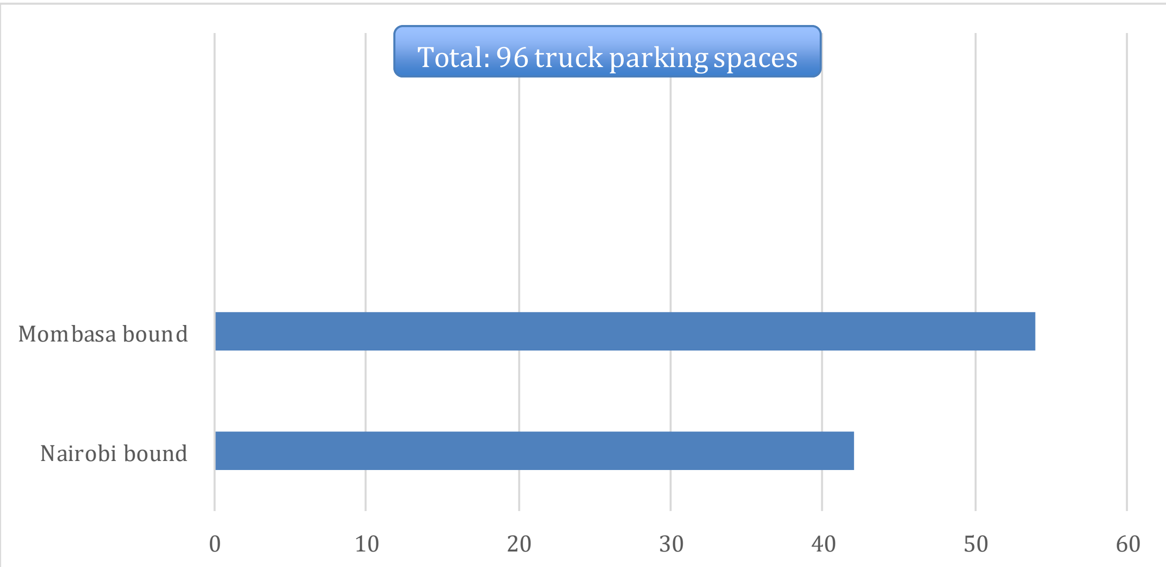

Figure 5.2 Parking Requirements Summary

Source: Author, 2018

The MnDOT as presented in chapter three (See equation 3.1) using the inputs shown below, yields a truck parking demand of 120 spaces. This assumes that, of the total mainline traffic stopping in Mlolongo, 45% are trucks. This assumption is based off the average volume of trucks compared to total traffic captured by the HSWIM (See Table 5.3):

Table 5.3 Total Traffic Captured by the HSWIM

Variable		Data
Average Annual Daily Traffic	AADT	73,503
Total percentage of mainline traffic stopping at rest area	P	14%
Design hour usage	DH	0.090377
Percentage of Truck parking spaces	Dt	45%
Seasonal Peak factor	PF	1.15
Number of vehicles parked per space	VHS	4
NTSpaces		120

Source: Author, 2018

To determine the parking demand through McShane's (1990) model, the average parking durations in each zone in the study area, were obtained. Table 5.4 summarizes the inputs and results from the model from Zones A to F.

Table 5. 4 McShane's (1990) Model Results Summary

Zone	Parking capacity (veh)	Average parking Duration (Hrs)	Parking Turnover	Utilization	Max car hours	Utilization hours	Free hours(total)	Free hours(study period)	Required spaces	f	Parking Demand(spaces)
A	80	2.71	7.01	82.5%	1520.00	1254.00	266.00	3.33	9.01	0.85	8
B	110	2.97	6.40	54.5%	2090.00	1139.05	950.95	8.65	25.68	0.85	22
C	180	3.59	5.29	60.0%	3420.00	2052.00	1368.00	7.60	27.28	0.90	25
D	80	4.47	4.25	55.0%	1520.00	836.00	684.00	8.55	38.22	0.90	34
E	70	5.74	3.31	55.7%	1330.00	740.81	589.19	8.42	48.31	0.95	46
F	155	5.50	3.45	36.7%	2945.00	1080.82	1864.19	12.03	66.15	0.95	63
											197
F is the insufficiency factor to account for turnover.											

Source: Author, 2018

The parking demand obtained from McShane's model obtains 197 spaces, which in comparison to the other models is higher, as represented in Tables 5.3 and 5.4 respectively.

5.2 Demand Forecasting

5.2.1 Provision of parking spaces for compliant vehicles

Parking demand forecasting is key towards planning and provides basic data for the design of parking areas or rest side stations. The basic formula for estimating traffic growth was used to forecast the AADT and the parking demand in *Mlolongo* study area. The following assumptions were made with regards to the parking demand forecast, up to year 2030:

i. The traffic growth rate will remain 5% over the forecast period of 11 years to 2030.

ii. The percentage of trucks of the total number of vehicles will remain at 9%.

iii. The maximum Hours of Travel will remain as per current regulations throughout the forecast period.

The results of the traffic growth forecast are provided in Figure 5.3 below:

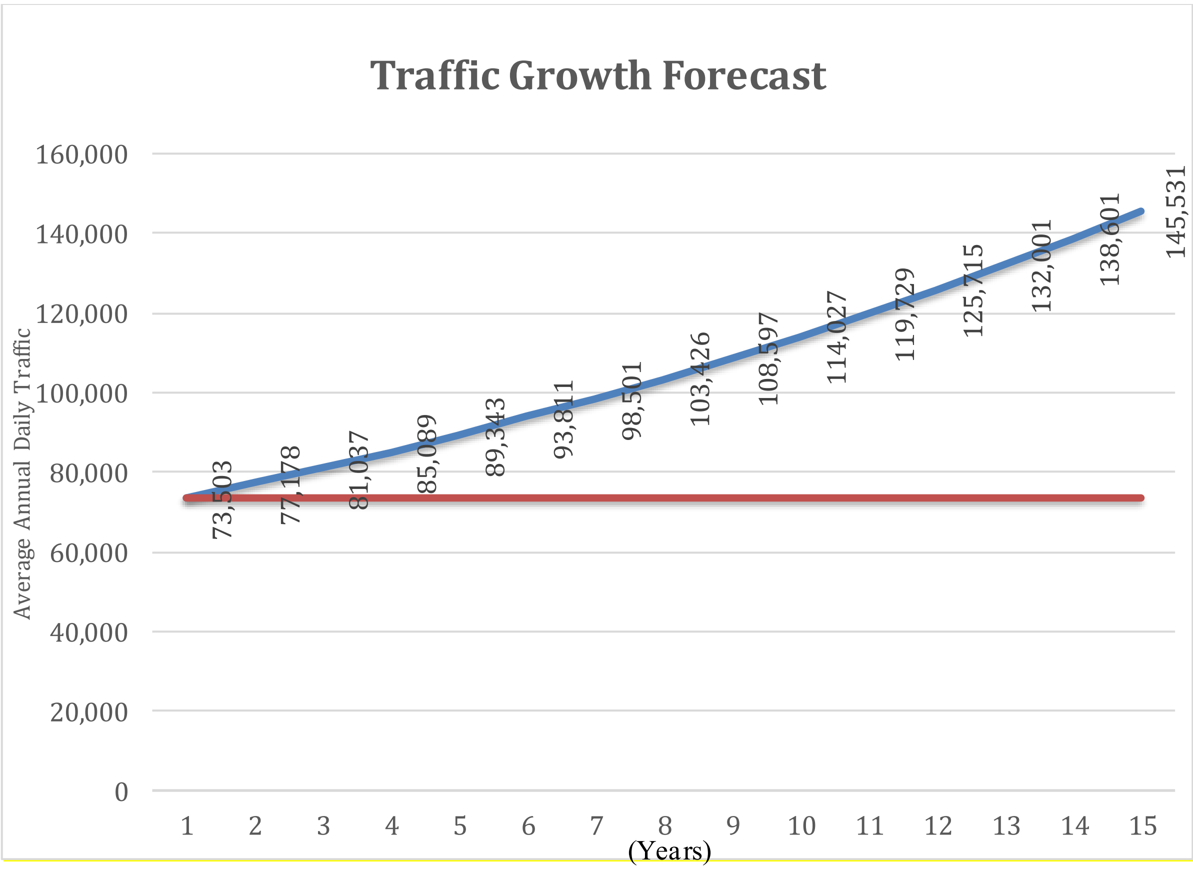

Figure 5.3 Traffic Growth Forecast to year 2030

Source: Author, 2018

The projected average annual daily traffic in 2030 is 145,531 vehicles/day. This is used to obtain peak hour parking demand for *Mlolongo*, which has been subdivided into Zone A to F. Table 5.1provides a summary of the parking demand per zone for the year 2030, whilst Figure 5.4 highlights the forecast with the step-by-step multiple linear regression.

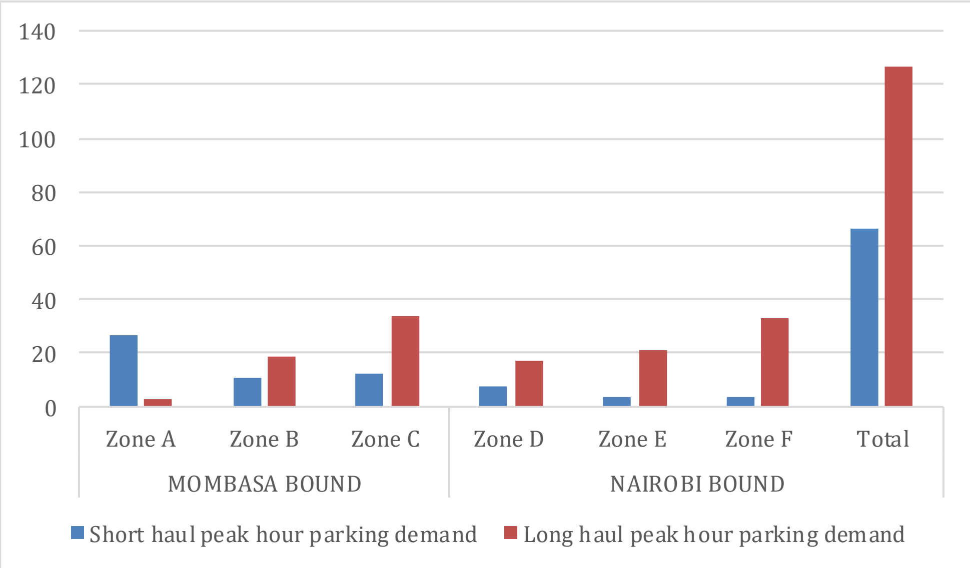

Figure 5.4 Parking Demand per Zone for the Year 2030

Source: Author, 2018

Table 5.5 Forecasted Parking demand for 2030

Summary	Quantity	Unit
Total parking requirement	194	parking slots
Nairobi bound parking requirements	87	parking slots
Mombasa bound parking requirements	107	parking slots
Percentage Nairobi Bound	43.3%	
Percentage Mombasa bound	53.2%	

Source: Author, 2018

Forecasts from the MnDot models (see equation 3.1) generate the number of truck parking spaces required in 2030 as 194 spaces. The summary is shown in Table 5.6 below:

Table 5.6 MnDOT Parking Supply Estimates for Year 2030

Variable	Abbreviation	Data
Average Annual Daily Traffic	AADT	145,531
Total percentage of mainline traffic stopping at rest area	P	14%

Design hour usage	DH	0.09
Percentage of Truck parking spaces	Dt	45%
Seasonal Peak factor	PF	1.15
Number of vehicles parked per hour per space	VHS	4
NTSpaces		216

Source: Author, 2018

The values obtained from MnDoT are close to the values obtained in the step-by-step model.

5.2.2 Provision of parking spaces for non-compliant vehicles.

For the peak hour truck parking demand requirements obtained for year 2030, provision will be made for impounding non-compliant vehicles for the regulation and enforcement of axle load controls. Since, the traffic volumes are forecasted over a fixed traffic growth of 5% across the design years, it is assumed that the percentage of non-compliant vehicles will also grow at the same rate. Comparative percentages of non-compliant trucks are used to derive the amount of space to allocate for parking (See Table 5.7).

Summary of Parking Provision for Non-Compliant Vehicles

Table 5.7 Summary of Parking Provision for Non-Compliant Vehicles

Direction	Parking Supply (2030)	%Non-compliant	Existing Holding Area	2030 Holding area Parking Supply Requirements
Nairobi bound Parking Requirements	87	20%	40	58
Mombasa bound Parking Requirements	107	6%	20	27
Total				85

Source: Author, 2018

Findings reveal that parking provisions for the 2030 truck parking design year at *Mlolongo* weighbridge area should provide for 85 non-compliant trucks. Further, given the available 60 spaces, an additional 25 spaces are required to cater for future non-compliant trucks, which account for 12.45% of the proposed parking truck spaces. This highlights the implications of the weighbridge operations on truck parking requirements in *Mlolongo* weighbridge area.

5.3 Proposed Parking Layout and supporting facilities

To alleviate the challenges faced by illegal truck parking in *Mlolongo* weighbridge area, problems associated with lack of adequate rest facilities, maintenance areas, parking and proper sanitation must be addressed when proposing interventions. Truck circulation within a proposed parking facility must also be resolved to ensure no bottlenecks arise along the Northern Corridor, or interruption of traffic flow within the auxiliary lane. Based on the survey results the study proposed the following facilities at Mlolongo weighbridge area:

i. Sanitation areas such as toilets, bathrooms, and water supplies.

ii. Safe parking;

iii. Medical services including an HIV/AIDS clinic;

iv. Truck maintenance and repair services;

v. Restaurant and refreshment areas; and

vi. Fuelling station.

Figure 5.5 below illustrates the proposed layout of the parking facility.

Figure 5.5 Proposed plan view of Mlolongo parking facility

Source: Google earth, 2018

5.4 Discussions

The *Athi River* weighbridge station serves as a major resting area for truck drivers along the Northern Corridor, and its operations contribute a great deal to the socio-economic dynamics of *Mlolongo* town. Given the prevalent highway shoulder parking by truck drivers and subsequent traffic flow challenges experienced around the weighbridge, this study sought to determine the truck parking requirements at the weighbridge by comparing the truck parking supply and demand. Volume data, travel, and parking demand surveys as well as truck driver interviews were conducted in order to make a data-driven assessment of the situation. This was done across 6 zones with 3 each for Nairobi and Mombasa bound areas along the highway, recognizing the unique characteristics contributing to truck parking demand.

Currently, *Athi River* weighbridge area does not have any planned parking facilities, except for holding areas which *only* accommodate non-compliant trucks. The Mombasa bound holding area has a capacity of 20 trucks, while the Nairobi bound station has 40 spaces. The Nairobi bound auxiliary lane handles up to 20% non-compliant trucks of the total truck volumes in a day. An additional 10 parking spaces are provided for weighbridge staff in each of the stations. Other trucks are forced to find alternative parking areas along the highway, in front of buildings and in garage yards. The analysis from this study determines the hourly peak parking demand for the area as 96 spaces for 2018, indicating a gap of up to 58% towards the supply of parking facilities at Athi River weighbridge area.

The HSWIM has introduced a new dynamic to weighbridge operations, significantly reducing the service time to an average of 1 minute per truck, subsequently reducing the length of queues. However, truck drivers still prefer to park in *Mlolongo*, as evidenced by a majority of the survey respondents. Whereas, forty-six percent of respondents stated that the weighbridge operations were satisfactory, the majority cited unfair treatment or solicitation by weighbridge staff as their primary concern. Additional information revealed that *Athi River's* weighbridge operations, including the impounding of non-compliant vehicles may affect parking requirements by approximately 13%. While *Mlolongo* remains the preferred destination for truck drivers to stop and rest, the choice to stay for longer durations may not be because of the weighbridge operations, rather, the services available to truck drivers that allow them to get the refreshment they need to continue with their trips.

Data collected on site was used to calibrate various models estimating parking demand. The multiple linear regression model represented a viable examination of the zones, and their contributions to overall parking demand. Notably, Zone A and B were heavily influenced by land use in *Mlolongo* town, with the heavy presence of trucks, passenger, and delivery vehicles. The model determines parking demand requirements for the area at 96 spaces for the year 2018. The number of short haul vehicles in the step-by-step model for zones along the highway segment (C-F) also corroborated truck volume data obtained from KeNHA on the *Nairobi-Machakos* route validating the short haul considerations.

The MnDOT model by Garber and Wang was also calibrated in order to estimate required parking supply. For 2018, this model obtains parking supply of 120 spaces required for the *Mlolongo* area. This model's findings are relatively similar to the step-by-step multiple linear regression model but did not account for variation of parking turnover between zones. McShane's model was also calibrated to determine parking supply, though this model proved relatively difficult to calibrate because it required predefined numbers of parking spaces in the zones and times in which the spaces were available throughout the study area. The model estimates parking supply by building on the parking capacity of the zone, as well as utilization of the parking slots over the study duration. Given broad estimates of parking capacities from the measured lengths of segments, the parking supply obtained from this model was obtained as 197 spaces, which when compared to earlier mentioned models, was higher. This model was therefore not carried forward to forecasting stage.

Present parking needs obtained for the study area were then forecasted to the year 2030 with an anticipated traffic growth rate of 5% to provide an approximation of future overall parking requirements. The AADT was forecasted for 11 years and then inputted in the multiple linear regression and the MnDOT models, where parking requirements of 194 and 216 spaces are determined respectively. The result from the step-by-step regression is adopted as peak hour truck parking requirement for 2030, for which parking improvement programs or plans should be based. Nairobi bound parking requirements were determined as 87 parking slots and Mombasa bound parking requirements determined as 107 parking slots. This reflects the results obtained from volume and parking studies with higher truck volumes along the Mombasa bound side of the highway, as well as higher parking accumulation volumes in Zone C.

This study established that the most important considerations for stakeholders of *Athi River* weighbridge station in the parking improvement program would be: to ensure that axle load control goes on without any key interruptions; and to provide secure and regulated parking; rest and refreshment areas; medical facilities with a HIV/AIDS clinic post; sanitation areas; as well as repair and maintenance services. Access to places of business should also be considered when making provisions for the facility, to ensure proper integration of transportation modes after parking. This includes consideration for walkways and access/restriction of other transportation players such as buses. Restrictions on hawking and vending within the facility should also be discussed in the planning stages.

Nonetheless, this study argues that the land around the weighbridge stations may not be adequate to accommodate the design parking requirements as well as supporting facilities. Consequently, considerations ought to be made for acquisition of land. This acquisition and proposed traffic circulation should serve to promote land use improvement, which is consistent with community goals and objectives as highlighted by the Nairobi Metropolitan Spatial Concept. Other considerations for parking improvement at the *Athi River* weighbridge area will include legal and engineering services, construction and financing. In the case of *Mlolongo*, a temporary parking facility may also be considered in order to handle the increasing demand in the short term.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Overview

This chapter discusses the conclusions and policy recommendations of the study. It also examines the research study objectives and determines whether they have been met. The study was conceived out of the need to identify the current and forecasted needs for truck parking along the *Athi River* weighbridge area. The ultimate objective of this study is to adopt a suitable model for the determination of truck parking requirements at the *Athi River* weighbridge and its environs.

6.2 Conclusions

6-2.1 Identify whether parking along Athi River is adequate to meet truck trucking demand

The study established that an overwhelming number of truck drivers at the Athi River weighbridge, encounter a shortage of truck parking facilities, especially for long-term overnight parking. Yet, truck traffic along the Northern Corridor continues to grow, further straining capacity. Several studies have indicated that the inadequacy of parking facilities for commercial trucks maybe associated with fatigue-related crashes involving those vehicles. The study identified *Mlolongo* as the preferred rest area for truck drivers. However, the majority prefer to park along the shoulders of the highway, due to a lack of designated parking areas, resulting in the accelerated deterioration of the pavement. This study estimated a shortfall of truck parking spaces for rest areas at Athi River weighbridge area. The parking requirements were determined by a multiple regression analysis and forecasted over the design period.

6.2.2 Establish whether the operations of the weighbridge affect truck parking demand

The study ascertained the peak parking demand in *Mlolongo,* as overnight, between 10:00pm and 6:00am, for truck drivers who preferred the early morning service at *Athi River* weighbridge. When truck drivers are tired, they need to leave the roadway as quickly as possible. However, the stopover is not always possible, as the truck driver's employers do not factor hours off duty, to allow the drivers to stop and rest during their journeys. The High-Speed Weigh in Motion

(HSWIM) weigh bridge facility ensures vehicles are directed into the static scale, in which operations have also been digitized, thus significantly reducing the service time. However, only

non-compliant trucks can park in the weighbridge holding areas as they redistribute their weight or awaiting legal action. Currently, there are no available legal parking facilities at *Athi River* weighbridge for compliant vehicles.

6.2.3 To determine considerations necessary to providing adequate truck parking at Mlolongo/ Athi River Weighbridge Station.

The demand drivers for the parking requirements were identified as the traffic volume represented by the average annual daily traffic (AADT), the percent of trucks traffic, the number of hours travelled, and the diurnal and seasonal variances dictated by operational efficiencies.

Parking accumulation that evaluated the number of vehicles at the study area, Parking load – space/hour usage of the parking facility, measured in veh/hr./day. Parking duration represented by the duration of time vehicles remaining in parked condition, expressed in hours and Parking volume measured by the actual number of vehicles parked at the Athi River Weighbridge Station in a day, expressed as veh/day were used to determine the adequacy of the study location.

6.2.4 To adopt a suitable model for future determination of truck parking demand at the Mlolongo/ Athi River Weighbridge Station.

Data collected on site was used to calibrate various models estimating parking demand. The multiple linear regression model represented a viable examination of the zones, and their contributions to overall parking demand. The study concluded that this is the model that closely reflected the location requirements, and therefore adopted.

The most vital supporting facilities and amenities for a parking improvement program were found to be sanitation and water areas, secure parking, restaurant and lounge areas, repair and servicing facilities and medical facilities.

6.3 Recommendations

This study identifies short- and long-term recommendations for the development of a parking improvement program for the Athi River weighbridge station area, such as:

- The study found out that the parking facilities for trucks were inadequate and recommends re organization of the weighbridge area to incorporate temporary truck parking facilities on either side of the highway, to reduce shoulder parking by truck drivers. This study suggests the fuelling station in Zone A and the private garages in Zone F as possible temporary solutions for consideration.

- The study found out that the weighbridge location has a moderate effect on the requirements for parking accounting for 19% of the total demand. It is recommended that the operational considerations for the weighbridge be expanded to include a parking improvement plan, consistent with the axle load control operations and the commercial character of land use of *Mlolongo* to enhance the security of truck parking.

- The analysis of field data collected demonstrated the need to develop capacity to collect, manage and analyse truck parking information that will provide decision makers in planning the facility investments. It is recommended that a Truck Information Systems be incorporated to ensure proper allocation of resources to address challenges faced.

- Analytical tools, such as the multi linear regression analysis be used to model current and future demand for truck parking facilities design in all weigh bridge locations.

6.4 Summary

The desk study lays ground for the economic appraisal of developing roadside amenities to provide parking and packaging bankable projects to attract private sector investment. In assessing the requirements of truck parking facilities, the study has demonstrated the need to undertake field studies that will determine the variables significant to the demand at the location. This is a departure from the standard schemes that provide design elements in a Traffic Control Centre, and provides a scientific basis of determining parking requirements to guide the design of parking facilities along a transport corridor.

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