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School of Engineering

DEPARTMENT OF CIVIL ENGINEERING

Vehicle-Size Selection for Road-based Transit Operating in Mixed Traffic –The Case of Nairobi Thika Highway

BY:

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Research thesis submitted in partial fulfillment for the Degree of Master of Science in Civil Engineering in the Department of Civil Engineering of the University of Nairobi

DECLARATION

I, Murimi Ngari, hereby declare that this thesis is my original work. To the best of my knowledge the work presented here has not been presented for a thesis in any other university. Citations from others' work have been clearly identified, their work acknowledged within the list of references.

Signed…………………………………………Date………………………………..

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This thesis has been submitted for examination with my approval as the University Supervisor.

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This thesis has been submitted for examination with my approval as the university supervisor

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Prof. F. J. Gichaga

DEDICATION

This research is dedicated to the following persons:

My late father Mr. Peter Ngari Minji who never lived to see the end of my study, but planted a spirit of learning in me.

My dear mother, Mrs. Grace Ngari whose unwavering faith in God has seen me through many challenges

My dear wife, Hannah Muthoni who has kept up the necessary pressure on me to complete my work

Our daughter and son, Nyaguthii and Ngari for giving me a reason to live and keep pushing

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ABSTRACT

Vehicle size and type is one of the principal factors influencing the efficiency of transit service. This study sought to develop an approach to the optimization and selection of transit vehicle sizes for an uncoordinated system operating in mixed traffic. Data was collected along an 11.4km portion of the Nairobi-Thika Highway in Kenya. The 11.4km portion was divided into four segments which are defined by major intersections along the highway. Data collected included classified traffic counts, visual occupancy surveys, speed measurements and the measurement of vehicle-plinth areas. The data collected was analyzed to determine ridership patterns along the highway, occupancy patterns for different vehicle types and Passenger Car Equivalencies for different vehicle types. The relationships between occupancy rates and vehicle size; and between Passenger Car Equivalence values and vehicle size were then established.

A model was developed that optimizes transit vehicle size based on occupancy rates achieved by different transit vehicle sizes and the road occupancy of a vehicle. The premise of the model is to maximize passenger occupancy in a vehicle while minimizing the road occupancy of the vehicle. Optimum vehicle sizes were determined for the first two segments as 45 and 56 seats respectively. These would minimize roadway congestion along these segments. Along segments 3 and 4, the flows that would result from the selection of a particular vehicle size for the peak passenger flows were established. Further investigations should be carried out on the effects of different vehicle sizes at bus stops. These include the passenger waiting times, berth occupancy, boarding and alighting times, among others

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ACRONYMS & ABBREVIATIONS

ADB – African Development Bank

APC – Automatic Passenger Counters

APEC – Associated Professional Engineering Services

AVL – Automatic Vehicle Location

BRT – Bus Rapid Transit

CBD – (Nairobi) Central Business District

CES – Consulting Engineering Services

GOK – Government of Kenya

GPS – Global Positioning System

ITDP – Institute for Transportation & Development Policy

JICA – Japan International Cooperation Agency

KEBS – Kenya Bureau of Standards

KMI – Kenya Motor Industry Association

LRT – Light Rail Transit

MOR – Ministry of Roads (Kenya)

MOT – (Kenya) Ministry of Transport

MRTS – Mass Rapid Transit System

NAMATA – Nairobi Metropolitan Area Transport Authority

NMA – Nairobi Metropolitan Area

NMR – Nairobi Metropolitan Region

O-D – Origin-Destination

Pass-km – Passenger kilometres

PCE – Passenger Car Equivalence

PCU – Passenger Car Units

Seat-km – Seat kilometres

SUV – Sports Utility Vehicle

TDM – Transport Demand management

TRB – (American) Transportation Research Board

TTI – Texas Transportation Institute

UMTA - Urban Mass Transportation Administration

Veh-km – Vehicle-kilometres

CHAPTER 1. **INTRODUCTION**

1.1 Background

The transport sector in Kenya is characterised by high costs for passengers and freight, weak public and private institutions, and low levels of investment. Public transport is usually over-crowded and inefficient with unreliable service operations, long waiting times and poor safety and security standards (MoT, 2009). This is typical of cities in developing countries where road-based public transport comes in a variety of physical and organizational forms. Many of these cities have a large component of unconventional or intermediate public transport (Vijayakumar 1986).

While these informal transit industries share generic characteristics, each paratransit industry has its own specific characteristics that reflect the environment of the city in which it operates. In attempting to improve this industry, the challenge is one of understanding the role and capacity of the informal transit industry (Graeff, 2009). Size of vehicle is a particularly important issue in the developing world because vehicles of different sizes are in common use and are frequently in competition with one another (Vijayakumar 1986).

One of the fundamental measures of traffic on a road is the volume of vehicles using the road in a given time interval. It is termed as flow and is expressed in vehicles per hour. The traffic using a road is composed of a variety of vehicles. However, the ultimate aim of travel is to transport men and goods. The number of people involved in travel is an important measure in transportation planning (Kadiyali 2002). For cities such as Nairobi in Kenya, where a large number of residents use some form of public transport, the focus of transportation policy should be on passenger throughput as opposed to vehicle throughput (Gonzales et al, 2009), that is, the efficiency of the transit service.

The efficiency of an urban public transport bus service depends on different factors: network structure; the distances between stops and routes; fare pricing policies; frequency of operation and the size and type of the buses used. These last two variables may be the most amenable to change, given that most of the former, apart from not being easy to change, are already well established and follow the criteria of satisfying the demand (Dell Olio et al, 2012). Other factors include; the regulatory framework, pricing, route planning, fleet size, revenue integrity, competition, and bus utilization, among others (Iles and Nielson, 2006).

Various sizes of vehicles are available for transit; ranging from vans, to minibuses, to standard buses, to high capacity buses. Each type of vehicle has a role to play, and to some extent all may be complementary to one another as part of the overall public transport system (Iles and Nielson, 2006). Many models for selecting suitable bus sizes have been developed (del' Olio et al, 2012). Most existing vehicle size selection models accentuate a trade-off between vehicle capacity cost and passenger waiting-time cost (Ceder, 2007). These models require extensive data collection efforts. In uncoordinated systems such as the case of Nairobi, the data collection effort required for some of the models is impractical.

This research studies the relationships between occupancy rates and bus size, Passenger Car Equivalence factors and bus size, and bus flow and bus size; within the so called paratransit systems. Models were developed and applied along a portion of the Nairobi-Thika Highway. Vehicle size selection criteria were developed with regard to the vehicle flows that would result from the selection of a particular bus size. Optimum vehicle sizes were determined for the first two segments as 45 and 56 seats respectively. This implies that buses between 51-seats and 62 seats would be most suitable along these segments.

1.2 Description of the Study Area

The (A2) Nairobi-Thika Highway is one of three major corridors linking Nairobi City to its suburbs and satellite towns (See Figure 1.1). This road is part of the classified international trunk road which originates from downtown Nairobi and extends to Moyale at the Ethiopian border. The highway links to the Nairobi City centre, several densely populated outskirts such as Githurai, Kahawa, Zimmerman, Kasarani, Mwiki; satellite towns including Ruiru and Thika as well as several major distant towns of Nyeri, Embu, Meru, Garissa, Nanyuki, Karatina, Mwingi, Matuu, Isiolo (Irungu, 2007). Between 2009 and 2012 the highway was upgraded from a two-lane dual carriageway to a four-lane dual carriageway with full control of access, and the construction of interchanges at all major traffic conflict points between Nairobi and Thika town (ADB, 2012).

The highway is served by a number of feeder roads including Outering Road, Kiambu Road, Kasarani-Mwiki Road, Kamiti, Eastern Bypass, among others (KeNHA, 2018) Road The study segment of the highway covers 11.4 kilometres from the Pangani interchange to Githurai (Figure 1.1).

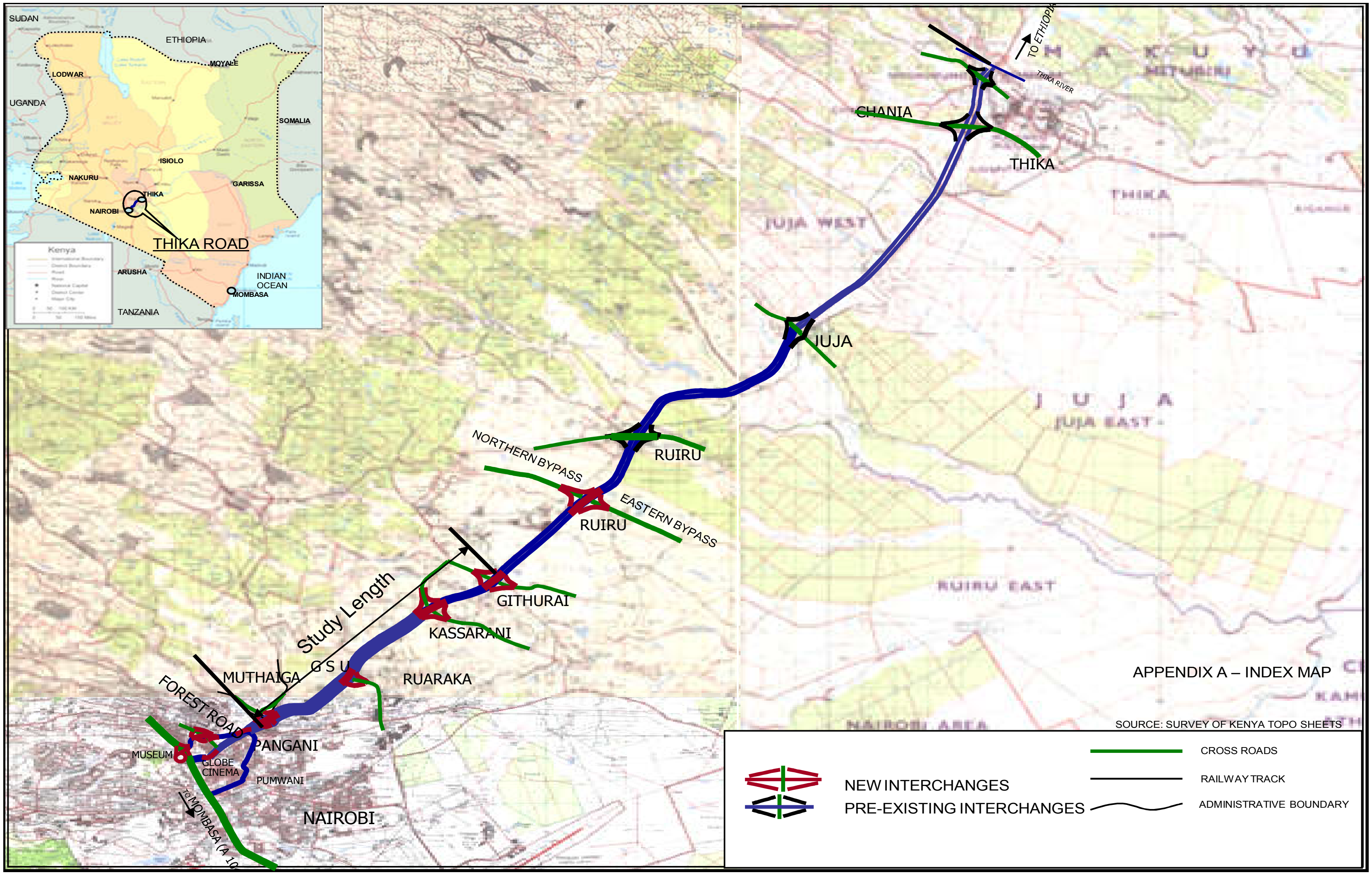


Figure 1.1 Study route on the Nairobi-Thika Highway

Source: Kenya National Highways Authority (2012)

1.3 Statement of the Problem

A good public transport system should move passengers from their origins to their destinations efficiently, reliably, comfortably, flexibly, and rapidly. These factors should make the use of public transport more attractive than driving. Unfortunately, the public transport system in Nairobi scores rather low on many of these characteristics.

The public transport system in Kenya is characterized by private ownership of transit vehicles. Vehicles of different seat capacities compete for the same passengers in the same space as shown in **Figure 1.2**. below.

Figure 1.2: 14-seater and 29-seater matatus competing for passengers at a bus stop
(Source: Author, 2017)

This means that the system capacity fluctuates depending on the sizes of the available vehicles. No methods have been developed for vehicle size selection in Kenya. Therefore, policy restrictions of low capacity vehicles from some areas have not been based on local research.

The utilization of vehicle capacity fluctuates across the day with overloaded vehicles during peak hours and many empty seats during off-peak hours (**Figure 1.3**)

Figure 1.3: Near-empty 29-seater matatus while passengers prefer 14-seaters during off-peak hours (Source: Author, 2017)

Distribution of seat capacity, passenger loads across modes, occupancy levels and efficiencies of different modes have not been established.

Passenger comfort fluctuates considerably across vehicles of different sizes and across different hours of day (**Figure 1.4**).

Figure 1.4: Passengers scrambling for seats during peak hours
(Source: Author, 2017)

The variations in passenger flows across different modes and across different hours of day have not been investigated. The relationship between occupancy rates and the seat capacity of transit vehicles along the Nairobi-Thika highway has not been investigated.

Roadway congestion especially during peak hours is a serious problem along the Nairobi Thika Highway (**Figure 1.5**). The impact of different transit vehicles on roadway congestion along the Nairobi-Thika Highway has not been investigated.

Figure 1.5: City-bound congestion during morning peak at the Pangani Interchange
(Source: www.mombo.co.ke, 2017)

The public transport system along the Nairobi-Thika Highway is characterized by unmet demand during peak hours and an oversupply of transit service during off-peak This results in long passenger waiting times in peak hours.

Figure 1.6: Buses queuing for passengers at the Githurai stage
(Source: www.kucomradesforum.com, 2017)

On the other hand buses take long to fill up during off-peak hours which still results in long in-vehicle times for passengers. The ability of vehicles with different seat capacities to meet the fluctuating demand has not been investigated.

1.4 Research Questions

This research seeks to answer the following questions:

1. Do transit vehicles contribute significantly to traffic volume along the highway?
2. Does transit ridership vary with time of day along the highway?
3. Is there a relationship between vehicle size and vehicle occupancy levels for transit vehicles along the highway?
4. Is there a relationship between transit vehicle size and the resultant demand for road space along the highway?
5. Is there an optimum transit vehicle size for a given passenger demand along the highway?

1.5 Study Objectives

1.5.1 Main Objective

This study sought to develop an approach to the optimization and selection of transit vehicle sizes for an uncoordinated system operating in mixed traffic. The proposed model involves the minimization of road occupancy by the transit vehicles, as measured using passenger car equivalence values; and the maximization of seat utilization as a function of vehicle size.

1.5.2 Specific objectives

1. To quantify the contribution of transit vehicles to the traffic flow along the highway
2. To determine the variation of transit ridership with time of day along the highway
3. To establish the relationship between vehicle size and vehicle occupancy levels for transit vehicles along the highway.
4. To establish dynamic the relationship between transit vehicle size and the resultant demand for road space along the highway
5. To determine optimum vehicle sizes for public transport along the study route

1.6 Scope of the Study

This study sought to establish a model for selecting and optimizing transit vehicle sizes in uncoordinated systems. The study was carried out along a portion of the Nairobi-Thika Highway. This research involved a route-level study along an 11.2km long portion of the Nairobi-Thika Highway. The study was on the efficiency of different transit vehicle sizes in terms of seat utilization, and the effects of different vehicle sizes on traffic flow. The major transit parameters studied include:

- Traffic volumes and composition along the highway
- Vehicle occupancy patterns in public and private vehicles along the highway
- Traffic speeds along the highway
- Passenger Car Equivalence factors for different vehicle sizes

Primary data was collected along the Nairobi-Thika highway from November 2014 to March 2015. Further data collection was done from February to August 2017

1.7 Limitations of the Study

Vehicle operating costs and transit user costs influence have been used as the major factors in transit vehicle size selection in many previous studies. In this study, vehicle operating costs and transit user cost data was not collected. Instead, vehicle plinth areas, occupancy and speed data were collected. The assumptions implicit in this approach are; (1) vehicle operating costs vary directly with vehicle sizes; (2) vehicle occupancy varies inversely with operating costs per passenger; and (3) vehicle speed varies inversely with travel time costs for passengers. This study was limited to an 11.2 kilometre long portion of the Nairobi-Thika Highway between Githurai overpass to the Pangani interchange. Only the Nairobi-bound traffic and ridership patterns were studied.

Further, data collection was carried out in late November and early December. This was during school holidays and thus, the data collection did not cater for seasonal variations in traffic patterns.

CHAPTER 2. **LITERATURE REVIEW**

2.1 Introduction

This chapter presents a review of existing literature on transit vehicle sizes. The relevance of transit vehicle sizes to transit size efficiency is discussed. A historical perspective of vehicle sizes with particular regard to Kenya and the existing regulatory framework for transit vehicles are discussed. Various models for optimization of transit vehicle sizes are discussed. Finally, a review literature relating to the methods of data collection and analysis adopted in this study is presented.

2.2 The Role of Transit-Vehicle Size in Transit Service Efficiency

Transit vehicle size is one of the principal factors influencing the efficiency of a transit system. Other factors include; the regulatory framework, pricing, route planning, fleet size, revenue integrity, competition, and bus utilization, among others. While different types and sizes of vehicles exist, each type of vehicle has a role to play, and to some extent all may be complementary to one another as part of the overall public transport system (Iles and Nielson, 2006).

Larger buses are usually more comfortable for passengers; they can carry a high proportion of standing passengers in greater comfort than smaller buses, which often have limited headroom. On the other hand, smaller buses can offer a higher frequency of service for a given passenger flow, greater route variation can also be achieved with smaller buses, without undue adverse effect on the service frequency. A small vehicle usually has better acceleration and maneuverability in traffic than a larger vehicle. Smaller size also means a smaller number of passengers boarding and alighting at each stop, so dwell times at stops will also be less. Thus, with regard to congestion, smaller and more maneuverable vehicles have an advantage. However, a very high service frequency may mean that there are often several vehicles running in convoy. This can create significant congestion compared with a single large vehicle carrying the same number of passengers (Iles and Nielson, 2006). Hemily and King (2002) found that small buses report vehicle reliability issues and high maintenance costs as the most frequently cited and highest-ranking concerns among operators.

2.3 A Historical Perspective of Transit Operations in Kenya

2.3.1 Legal and Regulatory Framework

The first local bus in Kenya was introduced in 1934 by the Overseas Transport Company of London, using a fleet of 13 buses on 12 routes. In 1966 the City Council of Nairobi (CCN) gave United Transport Overseas Services (UTOS) the then owners of Kenya Bus Services Ltd (KBS) a monopoly franchise to operate a bus service in return for a 25% shareholding stake in KBS. KBS remained the sole operator of bus transit till the 1970's (Kenya Bus Service, 2017)

As Nairobi's population grew following Kenya's independence, and the need to travel to the city center for work became more important, so did the need for public transport service. Matatus emerged to meet the unmet demand as the Kenya Bus Service (KBS) scaled down operations (Aligula et al., 2005). They continued to operate illegally in the city until 1973 when then President Jomo Kenyatta issued a decree officially recognizing matatus as a legal mode of public transport. The decree allowed matatus to operate without obtaining any form of licensing (Graeff, 2009).

In 1986, the state introduced Nyayo Bus Service Ltd which folded up in 1993 leaving the KBS in competition with a deregulated and un-taxed informal sector. Failure to regulate and tax Matatus then, was tantamount to subsidizing the sub sector and in effect allowing it to operate without paying its externalities' true cost. Public road passenger transport in Kenya has remained a private sector affair with no government support (no subsidy), no policy framework, no legal framework and no institutional framework (Kenya Bus Service, 2017).

In 1991, Stagecoach International of Britain bought a 75% stake in KBS from the United Transport Overseas Service, the original owners of KBS, and changed its name to Stagecoach - Kenya Bus. At around the same time, liberalization of the trade saw the entry of the second hand 14-seater (Nissan) mini buses into the PSV market. By 1998 after 7 years of operations, Stagecoach sold 95% of its shares to a group of Local Investors who renamed it Kenya Bus Services Ltd. The County Council of Nairobi had lost its 20% shares to Stagecoach through an equity rights issue, thereby eroding public sector participation the company (Kenya Bus Service, 2017).

In 2003, Legal Notice No. 161 was gazetted by the then Minister of Transport and Communications. The notice set out rules including that every public service vehicle including motor omni-buses, matatus and private hire vehicles was to be equipped and fitted with a seat belt. It also stated that every commercial vehicle whose tare weight exceeds 3,048 kilogrammes be fitted with a speed governor. These and other rules resulted in several benefits including a reduction in road accident rates by 73% within the first six months of implementation, improved security situation in public transport, among others (Chitere & Kibua, 2004). On the downside, the legal notice also prohibited the carrying of standing passengers. This negatively affected the cash-flow for the old bus companies, especially in Nairobi (Kenya Bus Service, 2017). It also effectively reduced highway capacity by lowering the bus capacities.

The Kenya Traffic Act of 2009 sought to consolidate and formalize various prior legal notices and regulations governing the transportation sector in Kenya. With regard to public transport, the Act sets out the licensing requirements for public transport vehicles, and gives legal guidelines for the ownership, operation and regulation of the public transit sector. It includes, under Subsidiary Legislation, by-laws of the various town authorities in Kenya including the designated routes for the city of Nairobi. The National Transport and Safety Authority Act of 2013 established the National Transport and Safety Authority (NTSA) as the overall body in charge of road transport safety and operations, including public transport.

2.3.1 Evolution of Transit Vehicle Types and Sizes in Kenya

The sizes and types of vehicles used as matatus in Kenya have evolved over the years. The Ford make omnibuses and converted pickups of the 1960s and 1970s led to the rise of workshops that specialized in the conversion of pickups into matatus by adding seats and windows. The 1980s saw the gradual introduction of Isuzu minibuses. Nissan type vans dominated in the 1990s and were fitted with 18 seats (Ommeh et al, 2013). The number of seats reduced to 14 following the implementation of Legal notice 161 of 2003 by the government of Kenya.

The 2000s also saw an almost complete shift from Nissan to Toyota vans (Ommeh et al, 2013). These are typically Japanese-made minibuses with about 14 seats. The network of scheduled bus routes has been gradually reduced as routes are abandoned and taken over by matatus (Gonzales et al., 2009).

The Kenya Traffic Act of 2009 defined a 'matatu' as public service vehicle having a seating accommodation for not more than twenty-five passengers exclusive of the driver, but does not include a motor car. It further defined a "motor omnibus" as a public service vehicle having seating accommodation for more than twenty-five passengers exclusive of the driver. The Act further defines the sizes and spacing of seats in public transport vehicles, provides body construction guidelines for PSVs, and prohibits public transport vehicles from carrying standing passengers.

2.3 Some Recent Transit Policy Developments in Kenya

2.3.1 Recent Public Transport Study Reports for Nairobi

Efforts by multiple agencies in Kenya with multiple (usually conflicting) mandates have resulted in a plethora of planning documents (also usually conflicting) which form the basis of different transportation projects (Gauff Consultants, 2014). The Metropolitan Growth Strategy for Nairobi of 1973, that was meant to run for 30 years was never fully implemented (MOT, 2009). The Integrated National Transport Policy of 2009 by Kenya's then Ministry of Transport stated the need to implement the Bus Rapid Transport (BRT) system that had been proposed for the Nairobi Metropolitan Region as part of the Vision 2030 economic blueprint.

The Institute for Transportation & Development Policy (ITDP 2014) carried out boarding/alighting surveys, visual occupancy surveys, transit speed/delay studies, and transfer surveys along various routes in Nairobi. A baseline travel demand model was developed in TransCAD software that enabled the formulation of a basic service plan for the much touted BRT system for Nairobi. The study mainly focused on transit within the city. However, it proposed, without elaborating, a Mass Rapid Transit System (MRTS) for the Nairobi-Thika Highway. APEC & CES (2011) identified nine corridors (8 radial corridors plus Outer Ring Road) for the implementation of MRTS systems and proposed a BRT system for the Nairobi Thika Highway.

In 2014, Gauff Consultants reviewed and made use of the findings of these and several other earlier studies including JICA et al (2006), JICA et al (2013) among others, in an attempt to develop a harmonized MRTS network across the Nairobi Metropolitan Region. The harmonization study evaluated the nine proposed MRTS corridors and goes further to develop a basis for microscopic planning such as the technical aspects of different transport modes. It proposes a two-phase implementation; Phase I up to the year 2030 and Phase II beyond 2030. In contrast to most previous studies, this study proposed a more decentralized transit network with several transit hubs in the Nairobi CBD. A network layout for MRTS on each corridor was developed. Figure 2.1 below is a layout the proposed Phase I MRTS service along the Nairobi-Thika highway and the associated cross-sectional passenger flows per day for each link in 2013.

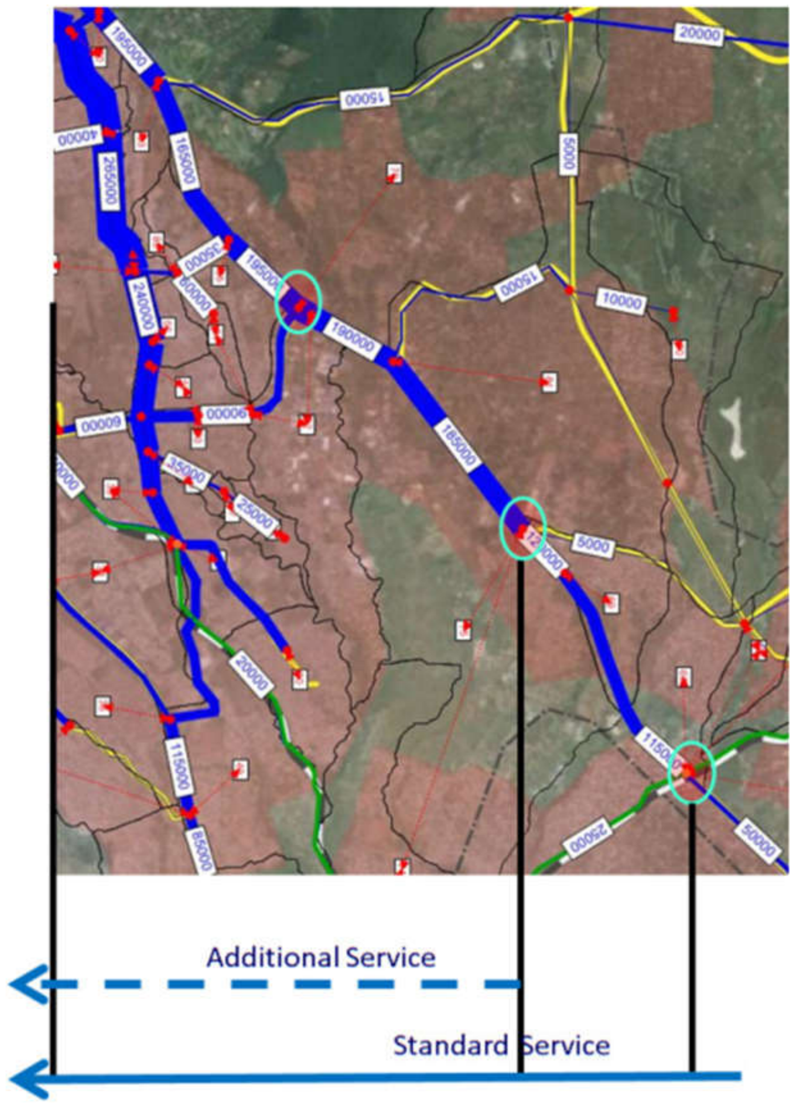


Figure 2.1: Proposed Phase I MRTS route on Nairobi-Thika Highway.
Source: Gauff (2014)

By setting the threshold for implementation of MRTS at 100,000 passengers, the study proposed that the system start at Ruiru (Standard Service on Figure 2.1) with additional service (shorter bus frequencies) from Githurai towards Nairobi CBD. The study goes further to project the daily passenger flows to 2030. With a maximum predicted flow of 395,000 passengers per day, the study concluded that a road-based MRTS will no longer be meet the demand and thus a complementary rail network will be necessary.

The study finally proposed the implementation of Bus Rapid Transit on the Nairobi-Thika Highway in Phase I and a commuter rail in Phase II. Basic operational organization, service plans and layout standards developed for the same. The study by Gauff Consultants is one of the most comprehensive public transport studies that have been conducted for Nairobi. However, it is necessary to validate the traffic forecasts made in 2014 by carrying out limited cross-sectional studies on the various corridors.

2.3.2 The Nairobi Metropolitan Area Transport Authority

The Integrated National Transport Policy of 2009 voiced the Government's concern over the fragmented nature of the institutional framework for the transport sector in Kenya. It further recommended the establishment of an independent institution at the metropolitan level to manage urban passenger transport services, operations and development of necessary infrastructure within the Nairobi Metropolitan Area (NMA). As a result, the Nairobi Metropolitan Area Transport Authority (NAMATA) was created in 2017 via a presidential decree (GOK, 2017). The full establishment of the authority was proposed in the Nairobi Metropolitan Area Transport Authority Bill of 2017. The bill defines the Nairobi Metropolitan Area to include the counties of Nairobi, Kiambu, Kajiado, Machakos and Murang'a. The function of NAMATA as defined in the bill is to oversee the establishment of an integrated, efficient, effective, and sustainable public transport system in the NMA. This would include formulation of transport policy, implementation of policies, regulation and coordination of transport policies, mobility plans and traffic plans.

NAMATA was, at the time of writing this thesis, in the process of implementing the proposals of the harmonization study by Gauff (2014). BRT lanes had been marked out on the Nairobi-Thika Highway. The authority was in the process of identifying suitable sites for BRT stops, major transfer stations and terminals. Terminals will require park and ride facilities while the stations will require sufficient median widths on the highway for passenger platforms and foot bridges. Enforcement and education to keep the BRT lanes free from trespassing vehicles will be necessary since no physical barriers have been provided. Another major challenge will be that of integration of the BRT system with the existing matatu system, especially on major feeder roads not served by the BRT.

2.3.3 Nairobi County Government Policies

The County Government of Nairobi, via Gazette Notice No. 4479 of 12th May, 2017, notified the public of a new network plan for public service vehicles entering Nairobi. The notice restricted public service vehicles from entering the Nairobi CBD. Several terminals outside the CBD were designated for different routes. For example, PSVs operating along the Nairobi-Thika Highway were required to terminate at the Murang'a Road Terminal B at Ngara. Two circular routes, limited to high-capacity vehicles only, were set out to transport commuters to and across the Nairobi CBD. No organization plans were revealed on the operations of these circular routes.

Several attempts at implementing the notice were made, the latest of which took effect from 3rd December, 2018. This was shelved after two days of severe congestion and protests (Daily Nation, 2nd Dec, 2018). It was not clear whether any reference was made to the existing studies on public transport in Nairobi or to NAMATA. Further no provision was made on the last mile connection for commuters from the designated terminals. The implementation of the plans in their current form is likely to result in an increase in private vehicles on the roads and the CBD as it punishes users of public transport.

2.3.4 Kenya Standards for Passenger Vehicle Body Construction

The Kenya Bureau of Standards (KEBS) was, at the time of writing this thesis, in the process of developing a standard for passenger vehicle body construction. According to the sixth draft (DKS 372: 2018), the standard aims to be of guidance to the passenger vehicle transport system for safety and comfort of passengers and general road safety requirements, and to harmonize the various sizes of passenger vehicles.

2.3.4.1 Bus Classes and Dimensions

The standard categorizes passenger vehicles into six classes as shown in **Table 2.1** below:

Table 2.1: Bus categorization and sizes in Kenya

Class	Description	Body length (metres)	Floor to roof Height (metres)
Class I	Micro-bus	Up to 7m overall	-
Class II	Mini Bus	7m-8m	1.7
Class III	Midi Bus	8m-10.5m	1.7
Class IV	Large Bus	>10.5m	1.8 (Interurban) 1.9 (Urban)
Class V	Single & Bi-Articulated bus	18-26m	1.8 (Interurban) 1.9 (Urban)
Class VI	Double Decker Bus	Max height: 4.7m	1.9

Source: KEBS (2018)

The standard also gives bus structure specification for each class above. Double Decker buses (Class VI) are restricted to urban use only while Large Buses and Articulated Buses (Classes IV & V) are further separated into urban type (IVA & VA) and inter-urban type (IVB & VB). Urban buses may include seated and standing passengers while inter-urban types shall carry only seated passengers.

The overall length for inter-urban large bus and articulated buses (Classes IVB & VB) is limited to 12.5 metres, 24 metres for urban single-articulated buses and 26 metres for bi-articulated buses (Class VA). Double decker buses (Class VI) may be articulated with similar restrictions on length. In all cases, however, the length of a single coach must not exceed 12.5 metres. The overall width for a passenger vehicle must not exceed 2.65 metres, while the floor height for urban buses must not exceed 900 mm.

2.3.4.2 Service Doors

Service doors are specified at a minimum width of 600mm for single doors and 1200mm for double doors. At least one door with minimum height of 1650mm shall be provided for Classes I, II, and III. Minimum door height of 1800mm is specified for Classes IV, V, and VI. Further, a minimum of two doors shall be provided for passenger capacity above 70, and three doors for passenger capacity above 105.

2.3.4.3 Maneuverability

The standard specifies a maximum outer turning radius of 12 metres while tracing an inner radius of not less than 5.3 metres as illustrated in Figure 2.2 below. This implies that while the outermost point of the vehicle traces a radius of 12.5 metres, the vehicle should move within the limits of a circular track 7.2m wide.

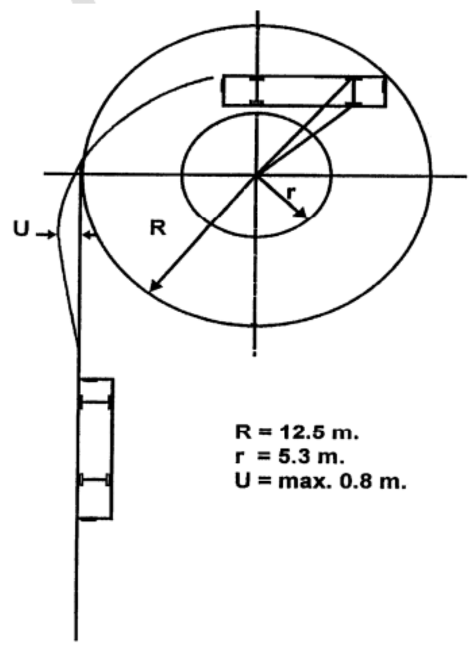


Figure 2.2: Vehicle maneuverability limits
Source: KEBS (2018)

This specification essentially places an upper limit on the size of a transit vehicle. It is also useful for intersection design.

2.3.4.5 Seat and Gangway Dimensions, and Seat Spacing

The standard specifies a minimum seat width of 400mm, legroom of 660mm (H in Figure 2.3) and 1420mm for seats arranged one behind the other and facing seats, respectively. Adding a 100mm foam thickness gives a row width requirement of 760mm. This is illustrated in Figure 2.3 below.

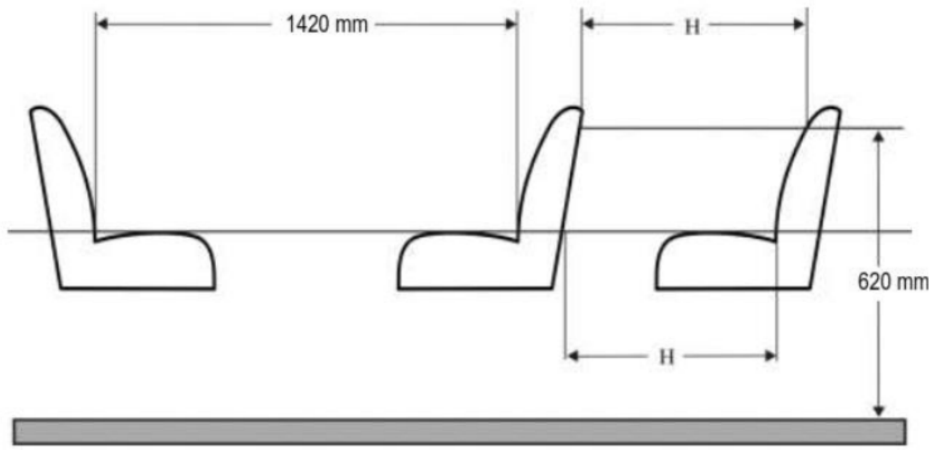


Figure 2.3: Seat spacing

Source: KEBS (2018)

Minimum gangway widths are given in **Table 2.2** below. These measurements are for vehicles without provision for standing passengers. Further, the minimum width for lateral gangways at the doors is given as 800 mm.

Table 2.2: Minimum width for lower gangways in buses

Vehicle Class	**Class I & II**	**Class III**	**Class IV, V & VI**
Min width of lower gangway (mm)	300	350	450

Source: KEBS (2018)

2.3.4.6 Passenger Capacity

The standard provides for calculation of the capacity N of a vehicle (both seated and standing) such that both of the following conditions are fulfilled:

$$N \leq P_s + \frac{S_1}{S_{sp}} \text{……………………2.1}$$

And

$$N \leq \frac{MT - MV - L*V - R*VX}{Q} \text{…………2.2}$$

Where,

P_S is the number of seating places;

S_1 is the surface area (m^2) available for standing passengers;

S_{sp} is the area assumed for one standing passenger (m^2 per standing passenger);

MT is the technically permissible maximum mass (kg);

MV is the unladen mass of the vehicle (kg);

L is the specified load of baggage (kg/m^2) in the baggage compartments;

V is the total volume (m^3) of the baggage compartments;

R is the specific mass of baggage in the roof area (kg/m^2);

VX is the total surface area (m^2) available for baggage to be carried on the roof;

Q is the mass (kg) assumed for load on each passenger seating and standing space

In the case of vehicle classes I & II, $S_1 = 0$. The values of Q, S_{sp}, L and R for the other classes of vehicles are given in **Table 2.3** below.

Table 2.3: Values for some vehicle capacity parameters

Class	Q (kg)	S_{sp} (m^2/standing passenger)	L (kg/m^3)	R (kg/m^2)
III	70	No standing passengers	100	75
IV	70	0.15	100	75

Source: KEBS (2018)

The standard does not give the above values for vehicle classes V and VI. It, however, seems reasonable to adopt the values given for class IV vehicles.

2.4 Transit Vehicle Size Optimization

The Kenya Motor Industry Association (KMI) (2017) argues that the optimum size of bus varies according to the passenger loads on its route. Very large buses become progressively less efficient as their occupancy falls, to the extent they can be the least efficient option where occupancy levels are consistently around 50% or lower. KMI concludes a medium bus (26-seater) is more economical and efficient than either a larger or smaller bus on routes where its occupancy is likely to be near 100%; while, a 14-seater minibus is most economical and efficient on the lowest passenger volume routes (retrieved from: http://www.kmi.co.ke).

Transit operations may employ minibuses, articulated buses, double-decker buses, standard buses, etc with varying degrees of passenger comfort and different number of seats. Optimal bus size entails trade-offs between vehicle size and operational variables for a given frequency of service (Ceder (2007). The use of smaller buses offers passengers a better service frequency for a given service capacity, but costs more to operate per seat provided. Within this trade-off there is an optimal bus size which maximizes social benefit (Oldfield and Bly, 1988).

Extensive transit vehicle size optimization studies were undertaken in the 1980s in developed countries when public policies started giving priority to local public transport with the aim of reducing traffic congestion in large urban areas. These studies were abandoned in the '90s concluding that it was more efficient to use smaller buses at higher frequencies (dell' Olio et al, 2012).

2.4.1 Vehicle Size Optimization Models

The major cost component of travel by public transport is the time it takes to travel. This time consists of walking time to the station; waiting time; time spent in the vehicle; and, sometimes, transfer time. Travel time increases with vehicle capacity and occupancy because, firstly, bulkier vehicles are often slower-particularly in congested conditions, and secondly, an increase in occupancy means more frequent and longer stops for boarding and alighting. On the other hand, increased frequency involves increased capital and operating costs. (Gronau, 2000).

Ceder (2007) reviewed several previous vehicle size optimization approaches. These included Jansson (1980) who assessed the cost of operating similar services at peak and off-peak during daylight. Gwilliam, *et al*. (1985) developed a simple cost minimization formula for the purpose of assessing the expected effects of the then proposed bus deregulation in Britain. Oldfield and Bly (1988) proposed a model that determines optimal bus size by assuming elastic demand; that is, demand that varies with passenger-trip cost. The model also considers the influence of changes in demand on road congestion. Jansson (1993) proposed a model that simultaneously optimizes vehicle size, frequency, and journey price. All passengers having the same origin and destination along the route are referred to as a group, and each group may have its own value of time. Shih and Mahmassani (1994) proposed a vehicle-size optimization model that requires the total demand matrix of the whole route system to be given, not the line demand. Lee *et al.* (1995) developed a model that attempts to optimize bus size not just for each route but also for each period of day, so that more than one bus size can be used on one route. Gronau (2000) investigated the viability of running two types of vehicles along the same route; one type consisting of smaller vehicles to cater for high time-value passengers, while the larger type caters for lower time-value customers.

Ceder (2007) further proposed a formula that trades-off between vehicle capacity cost and passenger waiting time cost. The assumptions are that operating cost per vehicle hour is the same (independent of vehicle size and load carried), average waiting time is half the headway, riding time is independent of vehicle size, and travel time and stopping time are independent. By minimizing the overall cost using the first derivative of the overall cost with respect to Z=0, the optimal vehicle size, Z_0 is obtained as follows

$$Z_0 = \sqrt{\frac{2C_bP}{C_w}} \quad \text{…………………………….. (2.3)}$$

Where: Z is the desired average occupancy in the max load segment, which corresponds to vehicle size, C_b is operating cost per vehicle-hour, P = number of average hourly passengers carried in the max load segment and C_w is the value of hourly waiting time. According to the square root formula, the optimal vehicle size is proportional to the square root of the number of passengers carried. The optimal size is also sensitive to changes in C_b and C_w. This being a cost minimization model, the assumptions that operating cost, travel time and stopping time are independent of vehicle size might result in a larger than optimum vehicle size being selected.

Since most of the above are cost minimisation approaches, they generally require a separate effort to calibrate the operation cost function. Other model requirements such as even headways, route-level OD for all passengers, passenger time costs, among others, would be difficult to determine for uncoordinated systems such as the Nairobi transit system

Dell' Olio et al (2012) proposed bi-level optimization model with constraints on bus capacity. The model assigns buses of different sizes to public transport routes by using the observed levels of demand on each route to optimizing the headways. At the upper level the model considers the optimization of the system's social and operating costs, these are understood to be the sum of the user's and operator's costs. At the lower level there is an assignment model for public transport with constraints on vehicle capacity which balances the flows for bus sizes and headways at each iteration. The optimization problem equivalent to the variational inequality $c(V^*).(V^*-V) \leq 0$ will be the following:

$$Min \sum_{s \in S} \int_0^{V_s} c_s(x)\, dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.4)}$$

s.a

$$\sum_{\gamma \epsilon R_w} h_r = T_w \qquad \forall w \in W$$

$$\sum_{\gamma \epsilon R} \delta_{sr} h_r = V_s \qquad \forall s \in S$$

$$V_l^s = \frac{f_l . V_s}{f_s} \qquad \forall l \in B_s, \forall s \in S$$

$$h_r \geq 0 \qquad \forall r \in R$$

where: W is a group of origin-destination pairs O-D, w is an element of group W, with i, j as centroids, T_w is the total number of journeys between O-D pair w for public transport users, l is a sign for designating a public transport route, R is the group of routes available for users of public transport, r: is a sign for designating a public transport route, R_w is a group of public transport routes associated with O-D pair w, $\bar{h}_r$ is the flow of passengers using public transport on route r, s is a sign designating a section of a public transport route, S is the group of route sections available for users of public transport, c_s is the cost of journey for users of public transport on route section s, δ_{sr} is the route section-route matrix: takes value 1 if route r passes by s and 0 in other cases, V_s is the passenger flow in route section s, v^l_s is the passenger flow in route section s using route l, f_l is the frequency of service of route l, f_s is the total frequency in route section s, and Bs is the Group of common routes where:

$$C_s = t_s + \left(\frac{\alpha}{f_s}\right) + \beta\left(\frac{V_s + \bar{V}_s}{K_s}\right)^n \text{..........................} (2.5)$$

Where: t_s is the travel time on the vehicle plus the price, f_s is the total frequency in route section s, α, n and β are calibration parameters, K_s = the capacity of route section s, V_s = total number of passengers in route section s, $\check{V}_s =$ flow which competes for the same capacity.

The model assumes that the users choose from all the possible routes that connect any two nodes in the public transport network, the chosen route minimises their total journey time (cost) (fare + journey time in vehicle + waiting time + access time). The model does not consider cost functions to increase as the number of seats increases.

2.5 Setting of Bus Frequencies

Furth & Wilson (1981) identified four frequently used methods used for setting frequencies for bus transit systems as policy headway, peak load factor, revenue/cost ratio, and vehicle productivity. This and other seminal approaches have later been extended and applied, either individually or in some combination. Gkotsalitis & Cats (2017) reviewed categories of methods for the same as those based on the passenger-load profile, those based on minimizing passenger and operator costs, and those that minimize unproductive cost (measured by empty-seats driven) and unserved demand (measured as bus overload). Ceder (2007) proposed four methods for frequency determination and divided them into two broader groups: max-load methods and load profile methods. Some of these methods are discussed below under, peak-load factor methods, load profile methods, minimization of user and operational costs, minimization of unproductive seats and unmet demand, and minimization of travel time.

2.5.1 Peak-load Factor Methods

One of the basic objectives in the provision of public transport service is to ensure adequate space to accommodate the maximum number of on-board passengers along the route. Based on the peak-load factor concept (Vuchic, 1978), the number of vehicles required to cater for the passenger demand in a particular hour is obtained by dividing the passenger volume on the maximum load section by the number of passengers assigned to each vehicle, as follows:

$$F_j = \frac{\bar{P}_{mj}}{\gamma_j . c} \quad \dots\dots\dots\dots\dots . (2.6)$$

Where $\overline{P}_{mj}$ is the average maximum number of passengers observed on-board in period j, c represents the capacity of a vehicle, and γ_j is the load factor during period j. This method assumes that the vehicle capacity, c is fixed. From this concept, Ceder (2007) proposed two methods based on the peak-load factor concept (ride check data). Both methods rely on the same equation given above but then they compare the resulting frequency with the minimum allowed frequency (reciprocal of headway). The higher of, the calculated frequency and the reciprocal of policy headway, is selected. In the first method (Method I), the number of vehicles required for period j is:

$$F_{1j}=\max\left\{\frac{P_{mdj}}{d_{oj}}, F_{mj}\right\}, \quad j=1,\ 2,\ldots\ldots,q \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.7)$$

$$P_{md} = \max_{i \epsilon S} \sum_{j=1}^{q} P_{ij} = \sum_{j=1}^{q} P_{i*j}$$

$$P_{mdj} = P_{i*j}$$

Where F_{mj} is the minimum required frequency (reciprocal of policy headway) for period j, there are q time periods; S represents the set of all route stops i excluding the last stop, i* is the daily max load point, and P_{ij} is a defined statistical measure (simple average or average plus standard deviation) of the total number of passengers on-board all the vehicles departing stop i during period j. The terms P_{mdj} and P_{md} are used for the (average) observed load at the daily max load point at time j and the total daily load observed at this point, respectively. The major assumption in this method is that the max load point remains the same through the day, thus the frequency calculation is based on a single stop. Therefore, in situations where the peak load point is at different stops at different times of day, crush loads or unmet demand would be observed on the other peak peak-load stops.

The second method (Method II) differs only in the consideration that the maximum load point at different hours of day might be at different stops. The frequency is determined as:

$$F_{2j} = max\left\{\frac{P_{mj}}{d_{oj}},\ \ F_{mj}\right\}, j = 1, 2, \ldots, q \qquad \ldots\ldots\ldots.(2.8)$$

Where $P_{mj} = max_{i \in S} P_{ij}$, which stands for the maximum observed load (across all stops) in each period j. These methods are suitable for cases where the peak loads are not very much higher than the loads along the rest of the route, as this would result in excess capacity being provided along all but the peak load segment.

2.5.2 Load Profile Methods

Ceder (2007) further proposed two methods to determine frequency and headway based on passenger-km rather than max load measure. The first load-profile method (Method III) considers a lower-bound level on the frequency or an upper-bound level on the headway, given the same vehicle-capacity constraint. It simply adds a third constraint to the peak load methods. Thus, frequency is calculated as:

$$F_{3j} = max\left[\frac{A_j}{d_{oj} \,.\, L}, \ \frac{P_{mj}}{c}, \ F_{mj}\right] \qquad \ldots\ldots\ldots\ldots\ldots (2.9)$$

$$A_j = \sum_{i \in S} P_{ij} \,.\, \ell_i, \qquad L = \sum_{i \in S} \ell_i$$

Where l_i is the distance between stop i and the next stop (i + 1), A_j is the area in passenger-km under the load profile during time period j, and L is the route length. The other notations were described earlier. In this method, the ratio A_j/L as an average representative of the load P_{ij}, as opposed to the max load (P_{mj}) in the second point-check method. This method guarantees, on the average basis of P_{ij}, that the on-board passengers at the max-load route segment will not experience overcrowding above the given vehicle capacity c. This method is suitable in cases where the planner wishes to know the number of vehicle runs expected, while relaxing the desired occupancy standard constraint and, at the same time avoiding situations where passengers are unable to board the vehicle. This method might result in crush loads for extended lengths.

Cedar (2007) introduces a second load profile method (Method IV) which establishes a level-of-service consideration by restricting the total portion of the route length having loads greater than the desired occupancy. Thus, frequency is computed as:

$$F_{4j} = max\left[\frac{A_j}{d_{oj}.\ L}, \frac{P_{mj}}{c}, F_{mj}\right] \qquad \ldots\ldots\ldots\ldots.. (2.10)$$

$$subject\ to\ (s.t.)\sum_{i\epsilon I_j}\ell_i \leq \beta_j.\ L,$$

Where mathematically $I_j = \left\{i: \frac{P_{ij}}{F_j} > d_{oj}\right\}$; in other words, I_j is the set of all stops in time period j, such that the load P_{ij} exceeds the product of d_{oj} and the frequency F_{4j}, and β_j is the allowable portion of the route length at period j in which P_{ij} can exceed the product F_{4j} . d_{oj}. The other notations in Equation (2.4) are as previously defined. By controlling the parameter β_j, it is possible to establish a level-of-service criterion. This method is an improvement on the preceding Method III. Developing the level-of-service criterion requires a separate effort

2.5.3 User and Operator Costs Minimisation

Hema & Angeline (2014) developed a model that generates a bus schedule that minimizes the waiting time costs for passengers and the operating costs for buses, subject to a load factor constraint and waiting time constraint. The objective function and constraints were as follows:

$$Min\left(C_1\sum_{i=1}^{n}(D_i * W_{ti}) + (C_2 * f * t)\right)\text{……… (2.11)}$$

Subject to:

$$C_{t1} = (A_d/(f * N_{lc})) >= L_{min}$$

$$C_{t2} = (A_d/(f * N_{lc})) <= L_{max}$$

$$C_{t3} = (T_{di}/(f * CLC)) <= 1$$

Where C_1 is waiting time cost in Rupees/minute, i is the stop index in the bus route, n is the number of stops on the route, D_i is the demand at each stop, W_{ti} is the waiting time for passengers at each stop, C_2 is the bus operating cost in Rupees/minute, f is the frequency of buses for the particular route, t is the trip time for the particular route, A_d is the average passenger demand on the particular route, N_{lc} is the normal bus capacity, L_{min} and L_{max} are minimum and maximum allowed load factors respectively, and T_{di} is the total demand from source to stop from each bus route. The frequency is computed using an iterative procedure. It requires the collection of at-stop passenger data rather than on-board data.

Li et al (2013) proposed an Expected Value Model (Liu, 2009) for optimizing multiple bus headways with bi-level functions of maximizing bus company profit while minimizing passenger waiting time cost as follows:

$$\max z_1 = E[f(x,\xi)] = E[I(x,\xi) - C_o(x,\xi)] \ldots\ldots\ldots\ldots\ldots (2.12)$$
$$\min z_2 = E[C_w(x,\xi)]$$
S.t.
$$b\left[\frac{t_k}{x_k}\right] \geq \sum_{s=1}^{S} \lambda_{ks} t_k, \qquad k = 1, 2, \ldots K$$
$$x_{min} \leq x_k \leq x_{max}, \qquad k = 1, 2, \ldots K$$

Where: the major objective function is to maximize z_1 is the expected bus company profit as obtained from the difference between total fare income ($I(x, \xi)$), and the operating cost of the company ($C_o(x, \xi)$). The second objective function is to minimize z_2, the expected waiting time cost for the passengers, and ($C_w(x, \xi)$) denotes the waiting time cost for the total passengers in one operating day. The first constraint ensures that the passenger demand of all the stations in each time period does not exceed the offered transportation capacity of all the buses departing in this time period. t_k is the length, in minutes, of one time periods (one day of operation is divided into K periods), x_k is the uniform vehicle headway in the k^{th} time period, λ_{ks} is arrival rate of the passengers at bus station s in time period k (there are S stations). x_{min} and x_{max} are the lower and upper limits, respectively, of the bus headway. It would be difficult to measure passenger waiting times in situations where competing bus companies operate on the same route with numerous interlining services.

Giesen et al (2015) describes a multi-objective transit frequency optimization with two objective functions, which attempt to minimize cost with respect to a set of O-D pairs and a given set of lines respectively. The formulation for the model is as follows:

$$min_{y,v,w} = \sum_{k \in K} \left(\sum_{a \in A} C_a V_{ak} + \sum_{n \in N^P} W_{nk} \right) \ldots\ldots\ldots\ldots (2.13)$$

$$Min_{y,v,w} = \sum_{l \in L} \sum_{f \in 1 \ldots m} \theta_f y_{lf} \sum_{a \in l} C_a$$

$$s.t. \qquad \sum_{f \in 1 \ldots m} y_{lf} = 1$$

$$\sum_{a \in out(n)} V_{ak} - \sum_{a \in in(n)} V_{ak} = b_{nk}$$

$$V_{ak} \le \theta_{f(a)} W_{nk}$$

$$V_{ak} \le \delta_k y_{l(a)f(a)}$$

$$V_{ak} \ge 0$$

$$y_{lf} \in \{0, 1\}$$

Where: K is a set of OD pairs for which k is a generic element, A is a set of boarding arcs (bus movement along street segments and walk paths between stop nodes), C_a is the cost of arc a, V_{ak} is the flow of OD pair k over arc a, W_{nk} is the waiting time multiplied by flow of OD-pair k in node n, N is the set of nodes with generic element n, L is th set of lines with generic element l, θ is bus frequency among a set of frequencies ($\theta_1 \ldots \theta_m$), y_{lf} is equal to 1 if frequency, f is assigned to line l, out(n), in(n) are the set of outgoing and incoming arcs of node n, respectively, and l(a), f(a) are the line and frequency corresponding to arc a, respectively. The model does not take into account the effects of bus capacity on passenger behavior or on the overall system performance.

2.5.4 Minimisation of Unproductive Costs and Unmet Demand

This is an extension of the cost minimisation methods aimed at minimising unproductive cost (measured by empty-seats driven) and unserved demand (measured as bus overload). Hadas & Shnaiderman (2012) took advantage of GPS, APC and AVL tools to define probability distributions for travel times and passenger demand. This information was used to define an analytical optimization approach to the determination of frequencies and vehicle sizes. Shnaiderman & Hadas (2018) extended their earlier model by including waiting time costs and transfers, and using it to jointly set frequencies for two routes sharing a stop. They considered both decentralized (two routes analyzed separately) and centralized systems (one company operating two routes). For the decentralized system, the goal is to minimize the expected cost for each route. The objective function is thus as follows:

$$ETC^j(H^j) = \sum_{i=1}^{I^j} \sum_{k=1}^{K^j-1} E\left[\zeta C_1^j + (1-\zeta) C_2^j | H^1, H^2\right] \ldots \ldots . (2.14)$$

Where ETC^j is the Expected Total Cost along route j, H^j is the headway along route j, i is the vehicle index (I^j is the number of vehicles on route j, j is the route index, j=1, 2., k is the stop index (there are K^j stops along route j), ζ is the ratio of surplus to shortage cost ($0 \leq \zeta \leq 1$), C_1 is the ratio average surplus to shortage cost per unit of travelling time, C_2 is the average waiting time per passenger, H^1 and H^2 are the headways for routes 1 and 2 respectively and are the decision variables. Headway is used in place of frequency since the two are reciprocal.

On the other hand, in a centralized system where one company operates two routes, or where the transit authority enforces routes' synchronization, the objective function is the Expected Total Costs for all vehicles and stops as follows:

$$ETC^j(O^1, H^1, H^2) = \sum_{j=1}^{2} \sum_{i=1}^{I^j} \sum_{k=1}^{K^j-1} E\left[\zeta C_1^j + (1-\zeta) C_2^j | O^1 H^1, H^2\right] \ldots \ldots . . (2.15)$$

Where O^1 is the departures' offset for one route from the start of the service. This offset becomes necessary in order to sychronize the arrival from the two routes at the transfer stop. This minimises the transfer time. O^1, H^1 and H^2 are the decision variables. These studies made use of advanced data collection tools. Manual data collection for the same models is possible but would be intensive. For example, a ride check can be used to measure unproductive seats while passenger waiting times have to be collected separately at stops.

2.5.5 Minimisation of Travel Time

Ibarra-Rojas et al (2015) define the frequency-setting problem as one of determining bus frequency such that travel times are minimized with a bounded fleet size as the constraint. The problem is formulated as follows:

$$[P] = \left\{ min \sum_{i \in V} \sum_{j \in V} D_{ij} T_{ij}^{l} : \sum_{l \in L} \lceil t^l f^l \rceil \leq F \right\} \ldots \ldots . . (2.16)$$

Where f^l is the frequency in buses per hour for each line $l \in L$, T_{ij}^{l} is the travel time between i and j via line l, D_{ij} is the demand for the origin-destination pair (i, j), t^l is the cycle time on line l,, and F is the maximum fleet size. However, this approach might result in the highest possible frequency only constrained by the fleet size. It is also not clear on how to determine the fleet size itself.

2.6 Transit Vehicle Size and Roadway Utilization

As stated in the previous section, travel time increases with vehicle capacity and occupancy because, firstly, bulkier vehicles are often slower-particularly in congested conditions, and secondly, an increase in occupancy means more frequent and longer stops for boarding and alighting (Gronau, 2000).

Except where by virtue of their numbers they are a direct cause of congestion, small buses can be advantageous in severely congested conditions. They are more maneuverable than larger buses and may cause less congestion per passenger in moving traffic than bigger buses, especially if bigger buses are not full. However, a very high service frequency may mean that there are often several vehicles running in convoy. This can create significant congestion compared with a single large vehicle carrying the same number of passengers (Iles & Nielson, 2006). It is hypothesized that the presence of a heavy vehicle in front of a passenger car causes the passenger-car driver to be more cautious because of the heavy vehicles large size and the resulting diminished sight distances (Kockelman & Shabih, 2000).

According to a brief by the Kenya Motor Industry Association (KMI, 2012), any vehicle (irrespective of its size) requires a space of circa 10 metres in front, 10 metres behind and two metres either side of its own body, while in motion. By that assumption, a 14-seater minibus occupies 150 sq m of road space (more than 10 sq m per passenger). A 60-seater bus occupies 220 sq m of road space (less than 4 sq m per passenger). It follows that transport of large numbers of commuters by minibus requires nearly three times as much road space as transporting the same number of people in large buses. Traffic composition, therefore, has a significant influence on road capacity and other design considerations.

2.6.1 Passenger Car Equivalence

Traffic composition has a significant influence on road capacity and other design considerations. Different vehicle types occupy different amounts of relative space on the roadway. Traffic flow data from classified counts needs to be transformed into ‘passenger car units’ (PCUs) by multiplying vehicular flow by the corresponding ‘passenger car equivalent’ (PCE). Highway Capacity Manual (HCM) 2010 defines PCE as “the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions". **Table 2.4** gives Passenger Car Equivalence Factors applicable to different vehicle types under different road conditions, as recommended by the Kenya Road Design Manual (1987)

Table 2.4: Typical Passenger Car Equivalence Factors used in Kenya

Vehicle Type	**Level Terrain**	**Rolling Terrain**	**Mountainous Terrain**
Passenger cars	1.0	1.0	1.5
Light goods vehicles	1.0	1.5	3.0
Medium goods vehicles	2.5	5.0	10.0
Heavy goods vehicles	3.5	8.0	20.0
Buses	2.0	4.0	6.0
Motor cycles, scooters	1.0	1.0	1.5
Pedal cycles	0.5	0.5	n.a

Source: GOK (1987)

Traffic on Kenyan roads is heterogeneous in nature, usually consisting of fast driven cars, vans, trucks and buses (MOR, 2009). Loose lane discipline prevails in many developing countries. This complicates the computation of PCE. Several methods have been proposed for field determination of PCE.

The 1965 HCM used relative reduction to determine PCEs for two lane highways using the Walker method. For multilane highways, PCEs were based on relative delay due to trucks. Thus the PCE value for vehicle type i was calculated as follows:

$$E_t = \frac{D_{ij} - D_b}{D_b} \text{……………………..2.17}$$

Where D_{ij} is the delay to passenger cars due to vehicle type i under condition j, and D_b is the base delay to standard passenger cars due to slower passenger cars.

Werner and Morral (1976) proposed the headway method to determine PCUs on level terrain at low levels of service. This considers that one of the primary effects of heavy vehicles in the traffic stream is that they take up more space. The PCE for trucks is thus calculated as follows:

$$E_t = \frac{\frac{H_m}{H_b} - P_c}{P_t} \text{.................................2.18}$$

Where H_m is the average headway for a sample including all vehicle types, H_b is the average headway for a sample of passenger cars only, P_c is the proportion of cars, and P_t is the proportion of trucks.

Chandra and Sikdar (2000) proposed a methodology for estimating PCE values for mixed traffic conditions, by expressing PCE as a function of vehicle area and speed. Thus, PCE for a particular vehicle type is formulated as follows:

$$PCE_i = \frac{V_c/V_i}{A_c/A_i} \text{...........................2.19}$$

where V_c and V_i are mean speeds of car and vehicle of type i respectively and A_c and A_i are their respective projected rectangular area (length * width) on the road.

Shalini and Kumar (2014) reported that Demarchi and Setti (2003) proposed the PCE's formula to eliminate the possible error for mixed heavy vehicles in the traffic stream, including interaction between multiple trucks types:

$$PCE = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1 \text{ ... ...2.20}$$

Where: P_i is the proportion of trucks of type i out of all trucks n in the mixed traffic flow, q_B is the equivalent passenger car only flow rate for a given v/c ratio, q_M is the mixed flow rate, and P_T is the truck proportion in the mixed traffic flow.

Chandra's method is most suited for conditions of heterogeneous traffic characterized by loose lane discipline (Mathew, 2014). Thus, Chandra's method was selected for this study.

2.7 Transit Vehicle Size and Capacity Utilization

The ultimate aim of travel is to transport people and goods. The number of people travelling is an important measure in transportation planning. This data can be gathered by noting the number of occupants in each vehicle as the volume count is being taken. (Kadiyali 2002).

A vehicle occupancy survey was carried out along the Nairobi-Thika Highway by CES and APEC in 2007. The average occupancy rates obtained then for private cars, 14-seater matatus, and 50-seater buses were as shown in Figure 2.4 below. Private cars had an average occupancy of 36%, 14-seater matatus had 94% occupancy, and large buses had 76% occupancy

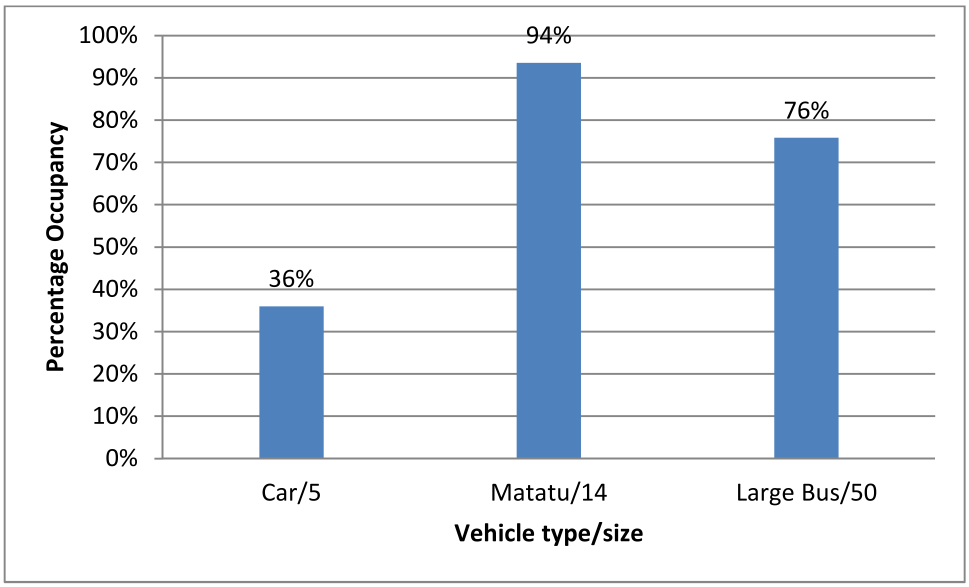


Figure 2.4: Vehicle occupancy rates for different vehicle sizes
Source: CES & APEC (2007)

Among the public transport vehicles, the smaller vehicles (matatus), achieved greater occupancy than the larger buses. The above pattern, therefore, implies that a vehicle size somewhere between the 14-seater matatu and the 50-seater bus would achieve the highest occupancy rate.

According to the KMI (2012) brief, the largest buses in Kenya's mass transport system are likely to be 60-seaters. However, very large buses become progressively less efficient as their occupancy falls, to the extent they can be the least efficient option where occupancy levels are consistently around 50% or lower. The brief concludes that a medium bus (26-seater) is more economical and efficient than either a larger or smaller bus on routes where its occupancy is likely to be near 100%;

in turn, a 14-seater minibus is most economical and efficient on the lowest passenger volume routes. Bus sizes should therefore be assigned to routes according to the passenger volumes on those routes, to achieve near full occupancy at the desired frequency of passage.

2.8 Summary of Reviewed Literature

2.8.1 Transit Vehicle-size Optimization Models

Source	Input Variables	Model	Comments
Ceder (2007)	• Passenger flows • Vehicle operation costs • Value of passenger time • Travel costs	$$Z_0 = \sqrt{\frac{2C_b P}{C_w}}$$ Where: Z is the desired average occupancy in the max load segment, which corresponds to vehicle size, C_b is operating cost per vehicle-hour, P = number of average hourly passengers carried in the max load segment and C_w is the value of hourly waiting time.	The model is data efficient since it considers only max load segment. However, it does not consider vehicle size influence on congestion. It also does not consider interlining routes i.e. routes with different origins-destinations sharing a stop. Travel times and stop dwell times are assumed to be independent of the vehicle size
Dell' Olio et al (2012)	• Passenger O-D • Routes available for transit • Service frequency • Travel times • Passenger flows	$$Min \sum_{s \in S} \int_0^{V_s} c_s(x)\, dx$$ s.a $$\sum_{\gamma \epsilon R_w} h_r = T_w \qquad \forall w \in W$$	The model considers the effect of transit on congestion. However, it assumes the bus frequency is fixed

	• Road capacity	$$\sum_{\gamma \epsilon R} \delta_{sr} h_r = V_s \qquad \forall s \in S$$ $$V_l^s = \frac{f_l . V_s}{f_s} \qquad \forall l \in B_s, \forall s \in S$$ $$h_r \geq 0 \qquad \forall r \in R$$ where: W = group of origin-destination pairs O-D, w is an element of group W, in which i, and j are centroids, T_w is the total number of journeys between O-D pair w for public transport users, l is a sign for designating a public transport route, R is the group of routes available for users of public transport, r: is a sign for designating a public transport route,	

		R_w is a group of public transport routes associated with O-D pair w, $\bar{h}_r$ is the flow of passengers using public transport on route r, s is a sign designating a section of a public transport route, S is the group of route sections available for users of public transport, c_s is the cost of journey for users of public transport on route section s, δ_{sr} is the route section-route matrix: takes value 1 if route r passes by s and 0 in other cases, V_s is the passenger flow in route section s, v^l_s is the passenger flow in route section s using route l, f_l is the frequency of service of route l,	

		f_s is the total frequency in route section s, and Bs is the Group of common routes where: $$C_s = t_s + \left(\frac{\alpha}{f_s}\right) + \beta\left(\frac{V_s + \bar{V}_s}{K_s}\right)^n$$ Where: t_s is the travel time on the vehicle plus the price, f_s is the total frequency in route section s, α, n and β are calibration parameters, K_s = the capacity of route section s, V_s = total number of passengers in route section s, $\check{V}_s =$ flow which competes for the same capacity	

2.8.2 Bus Frequency Determination Methods.

Source	**Input Variables**	**Model**	**Comments**

Peak-Load Factor Methods			Passenger volume divided by vehicle capacity
Vuchic (1978)	• Passenger flows • Vehicle capacity • Load factor	$$F_j = \frac{\bar{P}_{mj}}{\gamma_j . c} \quad \dots\dots\dots\dots\dots (2.16)$$ Where: $\bar{P}_{mj}$ design hour passenger load , γ_j is the load factor during period j, c = vehicle capacity.	This forms the basis for peak-load factor and load profile methods. It assumes that the vehicle capacity is set. It is impossible to set frequency in uncoordinated transit systems since there is no central control
Ceder (2007)	Method I • Peak passenger load • Vehicle capacity • Desired occupancy • Policy headway	$$F_{1j=\max\left\{\frac{P_{mdj}}{d_{oj}}, F_{mj}\right\}}, \ j=1, \ 2, \dots\dots, q$$ $$P_{md} = \max_{i \in S} \sum_{j=1}^{q} P_{ij} = \sum_{j=1}^{q} P_{i*j}$$ $$P_{mdj} = P_{i*j}$$ Where: F_{mj} - minimum required frequency (reciprocal of policy headway) for period j, S - the set of all route stops i excluding the last stop, i* is the daily max load point, and	A data efficient method because once the peak load point is determined, data is collected from only that point. However, a major assumption is that the max load point remains the same throughout the day. If the assumption fails to hold hold, crush loads and/or unmet demand would result along certain segments. It also requires policy headway to be available which does not apply to uncoordinated systems.

		P_{ij} - a defined statistical measure (simple average or average plus standard deviation) of the total number of passengers on-board all the vehicles departing stop i during period j. P_{mdj} and P_{md} are used for the (average) observed load at the daily max load point at time j and the total load observed at this point, respectively	
	<u>Method II</u> • Peak passenger load • Vehicle capacity • Desired occupancy • Policy headway	$F_{2j} = max\left\{\frac{P_{mj}}{d_{oj}},\ F_{mj}\right\}, j = 1, 2, \ldots, q$ Where: $P_{mj} = max_{i \in S}\, P_{ij}$, which stands for the maximum observed load (across all stops) in each period j.	This method ensures there is no unmet demand/ crush loads. However, if the loads at the peak points during different hours are substantially higher than at the rest of the stops, large unutilized capacity will result in the system.
Load Profile Methods			
Ceder (2007)	<u>Method III</u> • Peak passenger load • Vehicle capacity	$F_{3j} = max\left[\frac{A_j}{d_{oj}\ .\ L'},\ \frac{P_{mj}}{c},\ F_{mj}\right]$	This method uses average passenger loads (weighted by segment lengths) in addition to the load at max-load segment and policy

	• Desired occupancy • Policy headway • Segment lengths	$$A_j = \sum_{i \in S} P_{ij} \, . \, \ell_i, \qquad L = \sum_{i \in S} \ell_i$$ Where: l_i is the distance between stop i and the next (i+1), A_i is the area under the load profile (pass-km) in period j, and L is the route length.	headway, is in the previous method. This method might however result in crush loads along higher load segments especially if these segments are relatively short.
	Method IV • Peak passenger load • Vehicle capacity • Desired occupancy • Segment lengths	$$F_{4j} = max\left[\frac{A_j}{d_{oj}. \ L}, \frac{P_{mj}}{c}, F_{mj}\right]$$ $$subject\ to\ (s.t.) \sum_{i \in I_j} \ell_i \leq \beta_j. \ L,$$ Where mathematically $I_j = \left\{i: \frac{P_{ij}}{F_j} > d_{oj}\right\}$; in other words, I_j is the set of all stops in time period j, such that the load P_{ij} exceeds the product of d_{oj} and the frequency F_{4j}, and β_j is the allowable portion of the route length at	This method introduces a level-of-service criterion to Method III such that the risk of crush loads occurring is controlled using parameter β_j

		period j in which P_{ij} can exceed the product $F_{4j} . d_{oj}$.	
User and Operator Costs Minimisation			
Hema & Angeline (2014)	• User waiting time costs • Operator costs • Passenger demand • Segment lengths	$$Min\left(C_1\sum_{i=1}^{n}(D_i * W_{ti}) + (C_2 * f * t)\right)$$ Subject to: $$C_{t1} = (A_d/(f * N_{lc})) >= L_{min}$$ $$C_{t2} = (A_d/(f * N_{lc})) <= L_{max}$$ $$C_{t3} = (T_{di}/(f * CLC)) <= 1$$ Where C_1 is waiting time cost, i is the stop index in the bus route, n is the number of stops on the route, D_i is the demand at each stop, W_{ti} is the waiting time for passengers at each stop, C_2 is the bus operating cost, f is the frequency of buses for the particular route, t is the trip	This method attempts to minimize both passenger waiting times and bus operating costs while ensuring the passenger loads are within certain limits. It focuses on at-stop passenger experience while the onboard experience is taken care of by the constraints. It requires an iterative procedure to get the optimum frequency. Passenger waiting time costs have to be determined separately and may vary depending on passenger characteristics.

		time for the particular route, A_d is the average passenger demand on the particular route, N_{lc} is the normal bus capacity, L_{min} and L_{max} are minimum and maximum allowed load factors respectively, and T_{di} is the total demand from source to stop from each bus route.	
Li et al (2013)	• Bus company profit • Passenger waiting time cost • Passenger demand • Headway limits	$\max z_1 = E[f(x,\xi)] = E[I(x,\xi) - C_o(x,\xi)]$ $\min z_2 = E[C_w(x,\xi)]$ S.t. $b\left[\frac{t_k}{x_k}\right] \geq \sum_{s=1}^{S} \lambda_{ks} t_k, \quad k = 1, 2, \dots K$ $x_{min} \leq x_k \leq x_{max}, \quad k = 1, 2, \dots K$ Where: the major objective function is to maximize z_1 is the expected bus company profit as obtained from the difference between total fare income (I(x, ξ)), and the operating cost of the company (C_o(x, ξ)). The second objective function is to minimize z_2, the expected waiting time cost for the passengers,	Similar to Hema & Angeline (2014) in that the main objective is to minimize passenger waiting time cost and bus costs. Also similar in that the passenger loads are controlled using the constraints. It also introduces headway limits. At-stop data collection would be difficult to rely on in cases where competing bus companies operate on the same route with various interlining routes.

		and ($C_w(x, \xi)$) denotes the waiting time cost for the total passengers in one operating day.	
Giesen et al (2015)	• Route-level OD patterns • Passenger waiting time • Bus frequency	$min_{y,v,w} = \sum_{k\in K}\left(\sum_{a\in A} C_a V_{ak} + \sum_{n\in N^P} W_{nk}\right)$ $Min_{y,v,w} = \sum_{l\in L}\sum_{f\in 1\ldots m} \theta_f y_{lf} \sum_{a\in l} C_a$ $s.t. \quad \sum_{f\in 1\ldots m} y_{lf} = 1$ $\sum_{a\in out(n)} V_{ak} - \sum_{a\in in(n)} V_{ak} = b_{nk}$ $V_{ak} \leq \theta_{f(a)} W_{nk}$ $V_{ak} \leq \delta_k y_{l(a)f(a)}$ $V_{ak} \geq 0$ $y_{lf} \in \{0, 1\}$	This method has two objective functions, which attempt to minimize cost with respect to a set of O-D pairs and a given set of lines respectively.

		Where: K is a set of OD pairs for which k is a generic element, A is a set of boarding arcs (bus movement along street segments and walk paths between stop nodes), C_a is the cost of arc a, V_{ak} is the flow of OD pair k over arc a, W_{nk} is the waiting time multiplied by flow of OD-pair k in node n, N is the set of nodes with generic element n, L is th set of lines with generic element l, θ is bus frequency among a set of frequencies ($\theta_1 \ldots \theta_m$), y_{lf} is equal to 1 if frequency, f is assigned to line l, out(n), in(n) are the set of outgoing and incoming arcs of node n, respectively, and l(a), f(a) are the line and frequency corresponding to arc a, respectively	
Minimisation of Unproductive Costs and Unmet Demand			

Shnaiderman & Hadas (2018)	• Headway • Number of vehicles • Travelling time cost • Waiting time cost	$$ETC^j(H^j) = \sum_{i=1}^{I^j} \sum_{k=1}^{K^j-1} E[\zeta C_1^j + (1-\zeta) C_2^j \mid H^1, H^2]$$ Where ETC^j is the Expected Total Cost along route j, H^j is the headway along route j, i is the vehicle index (I^j is the number of vehicles on route j, j is the route index, j=1, 2., k is the stop index (there are K^j stops along route j), ζ is the ratio of surplus to shortage cost ($0 \leq \zeta \leq 1$), C_1 is the ratio average surplus to shortage cost per unit of travelling time, C_2 is the average waiting time per passenger, H^1 and H^2 are the headways for routes 1 and 2 respectively	This method minimizes the total systemwide costs by selecting headways that will minimize these costs. It attempts to minimize the unproductive seat-km and passenger waiting times with headways as the decision variable. It requires extensive on-board data that is best collected using advanced data collection tools.
Minimisation of Travel Time			
Ibarra-Rojas et al (2015)	• Fleet size • Route-level OD • Frequency • Travel time	$$[P] = \left\{ min \sum_{i \in V} \sum_{j \in V} D_{ij} T_{ij}^l : \sum_{l \in L} [t^l f^l] \leq F \right\}$$	This method attempts to minimize passenger travel time and the cycle time for buses with the fleet size as a constraint. However, this approach might result in the highest possible frequency only constrained by the fleet size. It

		Where f^l is the frequency in buses per hour for each line $l \in L$, T_{ij}^l is the travel time between i and j via line l, D_{ij} is the demand for the origin-destination pair (i, j), t^l is the cycle time on line l,, and F is the maximum fleet size.	is also not clear on how to determine the fleet size itself. It also does not appear to consider waiting times and boarding times

2.8.3 Passenger-car Equivalence Methods.

Source	**Input Variables**	**Model**	**Strengths**
HCM (1969)	• Measured delays • Vehicle types • Traffic conditions	$$E_t = \frac{D_{ij} - D_b}{D_b}$$ Where: D_{ij} is the delay to passenger cars due to vehicle type i under condition j, and D_b is the base delay to standard passenger cars due to slower passenger cars.	**<u>Strengths</u>** • Minimal data collection effort required **<u>Limitations</u>** • Applicable only to two-lane highways • Difficult to apply in uncongested conditions

Werner and Morral (1976)	• Headways • Vehicle classification	$$E_t = \frac{\frac{H_m}{H_b} - P_c}{P_t}$$ Where H_m = average headway for a sample including all vehicle types, H_b = average headway for a sample of passenger cars only, P_c = proportion of cars, and P_t = proportion of trucks.	**Strengths** • Suitable for level terrain with low LoS • Considers the road space occupied by different vehicle types **Limitations** • Does not consider the intermediate vehicle sizes between cars and trucks
Chandra and Sikdar (2000)	• Vehicle dimensions • Vehicle speeds	$$PCE_i = \frac{V_c/V_i}{A_c/A_i}$$ where V_c and V_i are mean speeds of car and vehicle of type i respectively and A_c and A_i are their respective projected rectangular area (length * width) on the road.	**Strengths** • Suitable multiple vehicle sizes • Suitable for different LoSs • Suitable for different road conditions **Limitations** • PCE values thus obtained are only applicable to the traffic and roadway conditions in which data was collected

2.9 Conclusions on Reviewed Literature

2.9.1 Gaps Identified in Existing Transit Vehicle-size Optimization

Major gaps identified in existing transit vehicle-size optimization approaches and models include the following:

1. Most existing approaches use costs only (mostly generalized costs) to optimize transit vehicle sizes. The fact that different vehicle sizes will achieve different occupancy rates, thus affecting the overall system capacity, is ignored.
2. Most previous approaches focus on the design of conventional bus systems which provide fixed-route, fixed-schedule, and coordinated operation. Such approaches would be simply impractical to apply to the uncoordinated transit systems with varying vehicle sizes that characterize the Kenyan public transport system
3. The data collection requirements for the previous approaches are also unsuited to the uncoordinated transit systems with several interlining routes, unscheduled stops and considerable bunching that occurs at bus stops along the Nairobi-Thika Highway.
4. It is expensive to collect the data necessary for the application of the existing models for the Nairobi-Thika highway due to the numerous data collection points that would be necessary.

2.9.2 Conclusions on Bus Frequency Setting Methods

All the frequency setting methods reviewed in this study are based on the allocation of seat-km on buses to passenger-km and then minimizing an aspect of cost such as waiting times, travelling times, vehicle-operating cost, and unproductive seat-km, among others. However, the frequency determination methods reviewed generally consider bus capacity as a decision variable. None of the methods explain how to determine the capacity in the first place. Further, the resulting frequency implies a certain level of demand on the road space. This is a particularly important factor when the transit system operates on a road space shared by other vehicles. This study attempted to determine a frequency that minimizes road space demand

2.9.3 Conclusions on Passenger-car Equivalence Methods

Most existing methods for estimating PCE values are based on measured delay caused by a vehicle relative to the delay caused by a passenger car. As a result, many of them are suited for data collected during periods of low Level-of-Service. Most applications of PCE values make use of the standard conversion factors provided in manuals such as the values given in the Kenya Road Design Manual (1987). These values are not easily adaptable to certain applications such as where marginal increases in vehicle sizes are considered. The method proposed by Chandra and Sikdar (2000) is adaptable to different vehicle sizes, different operating conditions and different terrains.

CHAPTER 3. **MODEL DEVELOPMENT**

3.1 Introduction

This chapter describes the transit vehicle size optimization model proposed from this research. The variables chosen for the model and their interrelationships are presented. A flowchart is given of the procedure of calibration and application of the model. Assumptions made in the model are also presented.

3.2 Overview of the Model

The transit vehicle size optimization model proposed in this research is a simulation model that seeks to identify the optimum vehicle size for public transport. It computes the resulting flow of transit when a particular vehicle size is selected for the measured transit demand. Most models discussed in the previous section seek to minimize vehicle operation costs as well as road user costs. The proposed model accentuates a trade-off between maximizing the occupancy of public transport vehicles while minimizing their contribution to congestion for a given level of demand. The method allows the selection of different vehicle sizes for different hours of day depending on the demand

3.3 Flow Chart for the Proposed Transit Vehicle Size Optimization Method

Figure 3.1 below is a flow chart illustrating the procedure followed in development and application of the transit vehicle sizing method proposed in this research. The procedure may be described as follows:

Step 1: The model inputs are defined. These include: vehicle occupancy rate, vehicle sizes, passenger car equivalence factors, and the hourly passenger flows along a link.

Step 2: Input data collection: Occupancy data is collected directly from the field; occupancy rates are then computed by expressing the level of occupancy as a fraction of the vehicle capacity; vehicle size is a decision variable; passenger car equivalence is obtained by applying the method proposed by Chandra and Sikdar (2000); passenger demand is measured as ridership from cross-sectional counts and occupancy surveys.

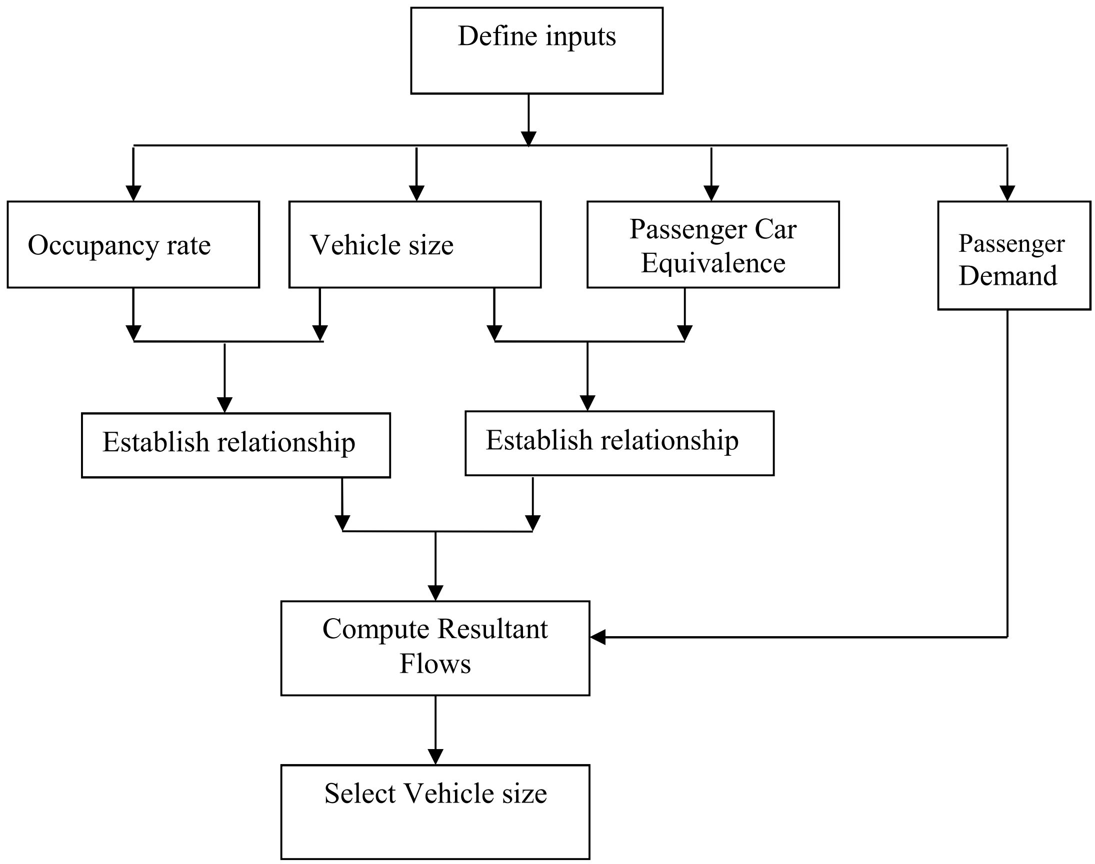


Figure 3.1: Flow chart of the proposed method

Step 3: A mathematical relationship is established between occupancy rate and vehicle size, and between Passenger Car Equivalence and vehicle size.

Step 4: The resultant traffic in Passenger Car Units is established from the variables for different sizes of vehicles. A plot is then made of vehicle size against the resultant flow.

Step 5: A vehicle size is selected that minimizes the resultant flow

3.4 Model Formulation

Based on the peak-load factor concept (Vuchic et al, 1978), the number of vehicles required to cater for the passenger demand in a particular hour is given by:

$$F_j = \frac{\bar{P}_{mj}}{\gamma_j . c} \qquad \dots\dots\dots\dots\dots (3.1)$$

Where $\overline{P}_{mj}$ is the average maximum number of passengers observed on-board in period j, c represents the capacity of a vehicle, and γ_j is the load factor (occupancy rate) during period j. In an uncoordinated transit system where the service is demand responsive and with no central operations agency, the frequency is not set. The capacity of transit vehicles varies, and the load factor is difficult to enforce. In order to overcome these challenges, the equation was adapted as follows:

- Maximum number of passengers observed on-board in period j, $\overline{P}_{mj}$ remains unchanged
- The load factor, γ_j is replaced with occupancy rate on vehicle size Z during hour j, and the notation becomes γ_{zj}.
- Vehicle capacity remains unchanged but the notation changes to Z
- Frequency, F_{zj} becomes the flow of Z-sized vehicles in hour j

Thus equation 3.1 above becomes:

$$F_{zj} = \frac{\bar{P}_{mj}}{\gamma_{zj}.Z} \qquad \dots\dots\dots\dots\dots (3.2)$$

Where, F_{zj} is the count of vehicles of size Z that would be observed during the design hour if vehicle size Z is used.

In order to measure the contribution of vehicle size Z to congestion along a roadway, the flow of vehicles is converted into the equivalent passenger car units by multiplying the equation by the PCE value of vehicle size Z. Further, lower and upper bounds for occupancy level are introduced in order to avoid crush loads or very low occupancy levels. Equation 3.2 thus becomes:

$$F_j = \frac{\bar{P}_{mj} * E_z}{\gamma_{zj}.Z} \qquad \dots\dots\dots\dots\dots (3.3)$$

$$\gamma_{min} \leq \gamma_{zj} \leq \gamma_{max}$$

Where F_j is the resultant flow of vehicles in hour j, in passenger car units, and E_z is the Passenger Car Equivalence for vehicle size Z. The other notations are as previously defined.

A model is proposed whose objective function is to minimize the flow of vehicles as calculated using Equation 3.3 above. Constraints to the objective function are given by the lower and upper bounds of the occupancy rates, and bus dimension limits set by the Kenya Bureau of standards. Thus, the model formulation is as follows:

$$Min\ F_j = \frac{\bar{P}_{mj} * E_z}{\gamma_{zj}.Z} \qquad \dots\dots\dots\dots\dots (3.4)$$

s.t.

$$\gamma_{min} \leq \gamma_{zj} \leq \gamma_{max}$$

$$Z \leq Z_{k\ max}$$

γ_{min} and γ_{max} are the lower and upper bounds for the occupancy rate. $Z_{k\ max}$ is the maximum capacity for a vehicle of a particular class. The maximum capacity of a particular vehicle class was determined by designing a layout for a bus for each of the classes spelt out by the Kenya Bureau of standards, using the parameters provided in the standard. The maximum number of seats that can fit into a bus while adhering to the standards were calculated for each bus type. The model is calibrated in the algorithmic procedure described in the flowchart shown in **Figure 3.1**. The inputs to the model are developed as follows:

- Passenger loads during hour j was achieved through cross sectional vehicle counts and occupancy surveys. The approach is premised on the method proposed by Kadiyali (2002). Thus the peak passenger load is computed as:

$$P_{mj} = \max_{i \in I} \sum_{n=1}^{N} P_{nij}\ , \dots\dots\dots\dots\dots (3.5)$$

  Where P_{nij} is the passenger load carried by mode n along route segment i in the j^{th} hour; N is the number of vehicle modes considered, I is the set of all route segments i along the study route, and j is the hour under consideration.

- Vehicle size, Z is a decision variable. Z is a random number picked from the set of positive integers.

- Occupancy rate, γ_{zj} is obtained from its relationship with vehicle size, Z. A mathematical relationship is established by plotting γ_{zj} against Z. From this the value of γ_{zj} can be obtained for any chosen value of Z, either by reading from the graph or by computing from the regression equation.
- The PCE values can be obtained by any suitable method that gives a PCE value for any vehicle size. In this research, the Passenger Car Equivalence values are obtained by applying the method proposed by Chandra and Sikdar (2000). This methods proposes that the PCE value can be obtained as follows:

$$PCE_i = \frac{V_c/V_i}{A_c/A_i} \qquad \text{(3.6)}$$

Where V_c and \$ V_i are mean speeds of car and vehicle of type i respectively and A_c and A_i are their respective projected rectangular area (length * width) on the road.

Detailed data collection procedures for each of the above inputs are presented in Chapter 4.

3.5 Model Assumptions

The following assumptions were made when formulating the transit vehicle size optimization model:

- There exists a relationship between vehicle size and the occupancy rate at a given level of demand
- There exists a linear relationship between the vehicle size and its passenger car equivalence value
- Measured transit ridership equals transit demand.
- All boarding and alighting takes place at the nodes between adjacent route segments.
- Transit vehicles operate in mixed traffic under uninterrupted flow conditions

3.6 Applications of the Model

The proposed transit vehicle size optimization model can be applied in the following ways:

- It can be used in the selection of the optimum transit vehicle size for uncoordinated transit systems operating in mixed traffic

- It can be used in assessing the contribution of different transit vehicle sizes to congestion
- It can be used to develop design data for bus lanes for proposed segregated traffic systems

CHAPTER 4. **DATA COLLECTION**

4.1 Preamble

This chapter describes the methods employed in the collection of both primary and secondary data for this study. In order to identify the data collection requirements including tools and personnel, a reconnaissance survey was first carried out along the study route. This was also useful in the sectioning of the study route, identifying survey stations as well as any anticipated constraints. Data was obtained from both primary and secondary sources. Primary data was collected along an 11.2km long portion of the Thika- Nairobi Highway. Secondary data was obtained through a desk study by reviewing existing literature. Literature sources for the study included the library, internet journals, various government reports and various traffic survey manuals.

4.2 Objectives of Data Collection

The main objective for data collection was to obtain data useful for measuring the ridership of vehicles along the study route but with particular emphasis on public transport ridership, hence the objectives of data collection included the following:

1. To establish the traffic flow rates and composition along the highway
2. To establish the speed-flow-density relationships along the highway
3. To establish the variation of vehicle occupancy rates for different vehicle types along the highway across the day
4. To establish the plinth area of various passenger vehicle types
5. To establish vehicle speeds along the highway

4.3 Data Collection Methods

Manual data collection was employed for the study using pencil and predesigned data collection sheets as follows:

- Roadside classified traffic counts
- Roadside speed studies
- Roadside vehicle occupancy surveys by the windshield method
- Vehicle plinth area determination from secondary sources

Each of the above is discussed in greater detail in Section 4.6 below

4.4 Reconnaissance

A reconnaissance of the study route was carried out between 10th and 15th November 2014 in order to identify the data collection requirements. The main objective was to section the route into links, identify survey stations, establish personnel requirements and test handheld tally counters. Following the reconnaissance survey the road was sectioned into four links (route segments) as shown in **Figure 4.1** and as described in **Table 4.1**.

Figure 4.1: Map showing the route segments defined for the study along the route

Source: Google Maps

Table 4.1: Details and length of each route segment along the study route

Link Number	Segment length (km)	Description
L1	3.2	Githurai flyover to Roysambu flyover
L2	3.8	Roysambu flyover to Ruaraka underpass
L3	3.3	Ruaraka underpass to Muthaiga interchange
L4	1.1	Muthaiga interchange to Pangani interchange

Source: Author

Sectioning was done on the basis of intersections with adjoining roads, location of important bus stops, roadway geometrics, observed traffic characteristics, and other features impacting on the traffic characteristics. The route segments described above were selected such that each contains a considerable length of basic freeway segment.

The lengths of the links were obtained from CES & APEC (2007). The actual data collection points were established along the route according to the particular data being collected.

4.5 Personnel and Tools

The personnel recruited for the data collection effort included one data entry clerk and a twenty eight enumerators and supervisors. A saloon car and two fourteen-seater vans were obtained to facilitate movement of the enumerators and supervisors. The vans were discontinued after the first day after they proved ineffective. Various stationery, tools and equipment such as pencils, reflective vests, tally sheets, tally counters, etc, were provided to the data collectors.

The enumerators were divided into teams according to the data types and the different survey stations in such a way that each station would have a reliever on hand at all times. The whole team was taken through training complete with tallying exercises along the highway one day prior to commencement of the main study.

4.6 Data Collection Procedure

Data was collected for three weekdays; Thursday 27th November, Monday1st December, and Tuesday 2nd December, 2014, for 12-hours per day from 6.30am to 6.30pm. The survey stations were different for each primary data types. Traffic counts and occupancy rates data was collected simultaneously. The survey team was based in Juja, Kiambu County. All tools and materials were provided to the enumerators during training ahead of the commencement date for the main data collection. On the first day, the team was transported from Juja to their respective survey stations so as to be ready to begin by 6.15am. This proved ineffective; hence, from day two, the enumerators used public transport to report to their stations.

Manual roadside data collection was adopted. The enumerators were provided with handheld tally counters but many found them rather complicated to use hence tallying with pencil and paper was allowed. The supervisors travelled along the road throughout the day to ensure instructions given were adhered to. Data collection would end at 6.30pm after which each enumerator would compile their data.

4.6.1 Classified Traffic Counts

There was one traffic count station along each route segment as shown in

Table **4.2**

Table 4.2: Traffic Count Stations

Traffic Count Stations (Category A) **Direction: Nairobi Bound**		**Associated Route Segment**
1	Midway between Githurai stage and Roysambu stage	L1
2	Safaripark footbridge	L2
3	NYS footbridge	L3
4	Midway between Muthaiga flyover and Pangani interchange	L4

The traffic counts were first divided into two main types; public and private transport vehicles and further categorized in terms of their seat capacities as shown in

Table 4.3

Table 4.3: Traffic count classifications

Public Transport Vehicles		**Private/commercial vehicles**	
Vehicle type	**Number of seats**	**Vehicle type**	**Number of seats**
10-seater matatu	10	5-10 seater passenger cars	5
14-seater matatu	14	3-4 seater commercial vehicles	3
		10-14 seater private van	11
29-33-seater bus	31	29-33-seater bus	30
50-52-seater bus	51	50-62-seater bus	55

Two observers (one for public transport and the other for private transport) at each survey station recorded the number vehicles passing them towards Nairobi at 15-minute intervals from 6.30am to 6.30pm. A third observer at each station served as the reliever to ensure continuous recording. Sample tally sheets are provided in **Appendix A1 and A2**.

4.6.2 Vehicle Occupancy Survey

The objective of carrying out vehicle occupancy surveys was to establish the average number of occupants vis a vis the capacities of vehicles in the different classes considered in the traffic counts, along the route and at different times of day. There was one survey station for every route segment as shown in **Table 4.4**

Table 4.4: Vehicle occupancy survey stations

Vehicle Occupancy Survey Stations (Category B) Direction: Nairobi Bound		**Associated links**
1	Footbridge at Zimmermann	L1
2	Safari Park Footbridge	L2
3	Survey of Kenya footbridge	L3

4	First footbridge towards Pangani	L4

The windshield method was used for collecting vehicle occupancy data. An observer would make an estimate of the number of occupants in random vehicles passing them and record in the respective vehicle class. Random sampling was used to make at least five observations for each vehicle type for each 15-minute interval between 6.30am and 6.30pm. The observers would stand on a raised point in order for them to see the inside of vehicles through the windshield.

For the case of large vehicles such as buses where it is not possible to count the occupants quickly, the observers would record the extent of occupancy as full, three quarters-full, two thirds full, half full, and so on. They would later convert these fractions to occupancy by multiplying them by the seat capacity of the respective vehicles. The data collected was recorded in tally sheets similar to that in **Appendix A3** and **Appendix A4**.

4.6.3 Mode-specific Space Mean Speed

This is a measure of the speed of travel over a measured distance, rather than at a single point. It is computed by dividing the length of the segment under consideration by the average travel time of the vehicles traversing it. The objective of carrying out speed surveys was to establish time taken by different vehicle modes to traverse a specified length of highway under low flow conditions.

For this study, a 50 metre long basic freeway segment was marked out along the Roysambu-Ruaraka Link (Segment 2). Stratified random sampling was used to collect data in order to include the different types of vehicles in the sample. One observer was stationed at the start of the section while a second observer, armed with a stop watch, stood at the end of the section. A third observer stood next to the second one to record the times on the datasheet. The first observer would select an oncoming vehicle at random and indicate to the other observers using a hand sign. He would use another hand sign to indicate when selected vehicle was passing his position and the downstream observer would start the stop clock. As the vehicle passes the downstream observer, he would stop the clock. The third observer would record the time. Data was collected for passenger cars, 10-seater matatus, 14-seater matatus, 26-seater minibuses, 33-seater minibuses, and 52-seater buses. The data was collected during off-peak hours (1400hrs to 1700hrs). The time taken by a vehicle to traverse the 50 metre section was recorded to the accuracy of 0.01 seconds in data sheets similar to that in **Appendix A5.**

4.6.3.1 Sample Size

The required sample size was computed as follows:

$$n = \frac{4s^2}{\varepsilon^2} \dots\dots\dots\dots\dots\dots\dots 4.1$$

Where n is the number of observations, s is an assumed standard deviation borrowed from previous studies, and ε is the acceptable error of estimation. The standard deviation, s was taken as 10km/h; adopted from Berry and Belmonte (1951). The acceptable error of estimation was set at 5 km/h. The minimum required sample size for each type of vehicle was thus obtained as 16. **Table 4.5** shows the sample size taken for each of the vehicle types.

Table 4.5: Sample sizes for speed study

S. No	Vehicle type	Sample size
1	Passenger cars	96
2	10-seater matatu	26
3	14-seater matatu	42
4	26-seater matatu	16
5	33-seater matatu	34
6	51-seater bus	52
7	62-seater bus	16

4.6.4 Vehicle Plinth Area

This refers to the road area occupied by a vehicle. A vehicle model survey was carried out at same station as the speed survey described previously. This was achieved by carrying out a 15-minute classified vehicle count for passenger cars only. Passenger cars were classified into five categories according on their shape and plan area. Example models of each class were explained to the observers. These were: subcompact cars (Toyota Vitz, Nissan March, Honda Fit, among others), saloon (Toyota Corolla, Mitsubishi Lancer, Nissan Bluebird, among others), hatchbacks (Toyota Fielder, Toyota Wish, Subaru Legacy, among others), SUVs (Toyota Harrier, Toyota RAV4, Toyota Landcruiser, among others), and double cab pickups (Toyota Hilux, Nissan Navara, among others). This data was recorded in the data sheets given in **Appendix A6.**

From each category of vehicles, one model was selected based on the researcher's experience of its ubiquity in Kenya. Toyota Vitz was selected as representative of subcompact cars, Toyota Corolla for saloon cars, Toyota Fielder for hatchbacks, Toyota Harrier for SUVs and Toyota Hilux for double cab pickups, For 10-seater matatus, one model; Toyota Townace, was taken as a representative model; while Toyota Hiace was taken as a representative model of 14-seater matatus. External dimensions of each of the categories were retrieved from the internet from http://www.automobiledimension.com/. For public transport buses, data on bus dimensions for various buses from 26-seaters to 62-seaters was provided by Banbros Limited, a bus body manufacturing company located in Kenya. Isuzu models were selected as representative of all buses. Futher dimensions for buses were obtained from the Draft Kenya Standard, Road Vehicles: Passenger vehicle Body Construction Specification (DKS 372:2018).

4.7 Problems and Accuracy in Data Collection

A number of problems were encountered during the data collection process including:

1. The transport vans that had been hired to transport the field team ended up being a source of delay in picking observers from different places.
2. The usual morning traffic congestion along the route would prevent some observers from getting to their stations on time especially those travelling to stations nearer Nairobi
3. The handheld tally counters were too few and some were faulty. This problem was further compounded by most enumerators' inability and unwillingness to use the tally counters.
4. Despite considerable training, some observers failed to appreciate the importance of diligence in the data collection
5. The high vehicle speeds encountered on the road made counting rather difficult especially the vehicle occupancy surveys. This also presented a danger to the enumerators on the roadsides
6. Adverse weather conditions and hunger took the toll on the field team as the day progressed thereby affecting their concentration

4.8 Solutions to Problems and Accuracy in Data Collection

To address the problems listed above, the following measures were undertaken:

1. To avoid morning delays, use of the hired vans was discontinued and observers were required to use public transport to travel to their stations and were compensated for the cost
2. By using their own means to travel, observers travelling to stations in congestion-prone zones were able to time their mornings and were compensated differently
3. When the handheld tally counters proved unpopular, the observers were trained on using pencil and paper to do the tallying.
4. The daily tallies were checked for errors and those observers who were noted to be careless were discontinued. Close supervision was conducted to ensure everyone was at their station at all times
5. To improve visibility during the occupancy survey as well as safety of the team, the observers were stationed on the up-ramp of the pedestrian footbridges. They were also trained on road safety and were required to were the provided reflective vests at all times
6. To cater for the welfare of the observers, clean drinking water was delivered to each station during the day. Lunch money was provided and the observers were required to carry packed snacks

CHAPTER 5. **RESULTS AND DATA ANALYSIS**

5.1 Introduction

The primary and secondary data collected during the study were analyzed and used to determine the ridership patterns along the study section. This chapter describes the analysis carried out on each data type and the combination of the different data types to meet the objectives of the study. Further the results of the analysis are discussed after each description of data analysis.

5.2 Traffic Counts

The traffic count data obtained over the three days was averaged and the mean taken for each 15-minute interval. Traffic values for every four 15-minute intervals was combined to have the data tabulated in 1-hour intervals. The variations of traffic counts for the different vehicle types was determined by plotting graphs of number of vehicles against time of day

5.2.1 Observed Traffic Patterns

Detailed traffic counts for each route segment are provided in **Appendix B**. A summary of the observed daytime traffic volumes and composition along the study route is shown in **Table 5.1** below. It was observed that there were more private cars along the study route than all the other vehicle types combined ranging from 15,739 cars on the Githurai-Roysambu segment to 34,781 cars along the Muthaiga-Pangani segment (Segment 1). The total number of vehicles observed for 12 hours ranged from 21,716 along the Githurai-Roysambu segment (Segment 2), 28,587 along the Roysambu-Ruaraka segment (Segment 3), 32,500 along the Ruaraka-Muthaiga segment, and 46,421 along the Muthaiga-Pangani segment (Segment 4)

Table 5.1: Observed Traffic Composition along the study route (2015)

	Private Vehicles					Public Transport Vehicles					
Route Segment	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**	**Distance (km)**
Githurai - Roysambu	15739	924	350	3	27	133	2877	674	989	**21716**	3.2
Roysambu - Ruaraka	19957	2436	462	15	59	102	2821	1419	1316	**28587**	3.8
Ruaraka - Muthaiga	22006	2449	461	65	35	102	3794	2295	1293	**32500**	3.3
Muthaiga - Pangani	34781	2846	879	100	43	88	4035	1792	1857	**46421**	1.1
											Tot =11.4

Figure 5.1 shows the percentage traffic composition for each route segment along the study route. Private cars dominated traffic along the four route segments constituting an average of 71.2% of the total traffic along the route. Private vans, minibuses and buses were the fewest at 1.9%. All public transport vehicles constituted an average of 20.3% of the total traffic volume; 0.4% 10-seater matatus, 10.9% 14-seater matatus, 4.8% 33-seater buses, and 4.3% 51-seater buses. All vehicle types generally increased towards the Nairobi CBD.

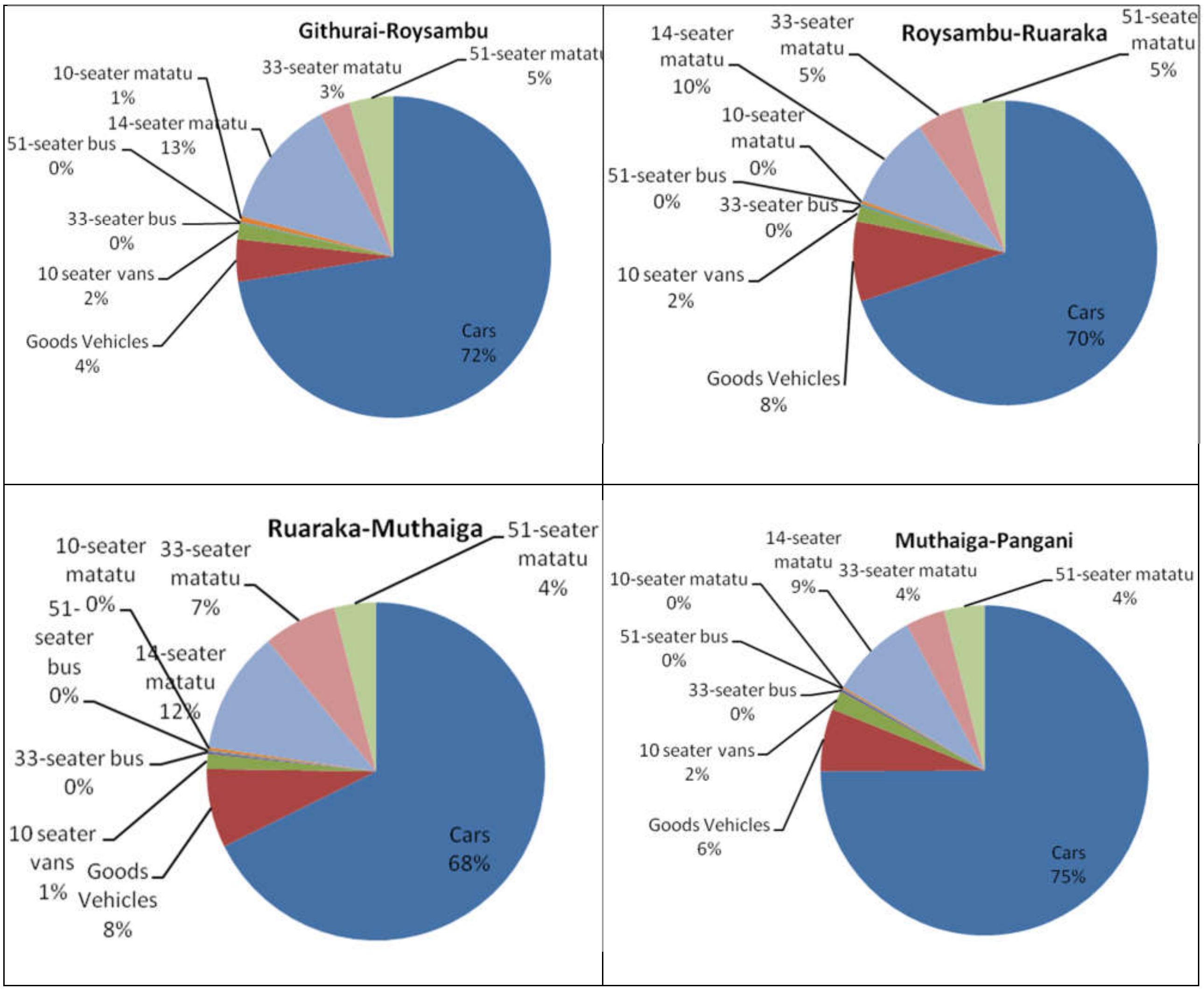


Figure 5.1: Daily traffic composition along the study route (2015)

5.2.2 Conversion of Counts into Passenger Car Units

Table 5.2 below gives the Passenger Car Equivalence values adopted to convert the traffic counts into Passenger Car Units. The values are as recommended in the Kenya Road Design Manual (1987) and Road Note 5. The traffic counts were converted into PCU by multiplying the count of each vehicle type with the respective equivalence factor. The traffic count stations were located on level terrain and thus values in the first column for level terrain factors were adopted.

Table 5.2: Typical Passenger Car Equivalence factors used in Kenya

Vehicle Type	**Level Terrain**	**Rolling Terrain**	**Mountainous Terrain**
Passenger cars	1.0	1.0	1.5
Vans (e.g matatus)	1.0	1.5	3.0
Goods Vehicles	2.5	5.0	10.0
Minibuses	2.0	3.0	4.5
Buses	3.0	4.0	6.0

Source: GOK (1987)

5.2.3 Established Average 12-hour Traffic

Since no 24-hour data was collected to enable conversion of 12-hour traffic data into 24-hour data, no attempt was made to determine the Average Daily Traffic. Thus, the term daily traffic shall refer to traffic flow occurring between 6.30 am and 6.30pm. Traffic volume values for four 15-minute periods within each hour were added so as to express the volume in hourly intervals.

The average hourly traffic in PCUs along each route segment is given in **Appendix C. Figure 5.2**, to **Figure 5.5** below shows the typical daily variation of traffic flow, in Passenger Car Units, along each of the four segments. Segment 1 exhibits a morning peak in the 6.30-7.30am hour with 3047veh/hour. The traffic flow then falls to a low of 1451veh/hr in the 2.30-3.30pm hour before rising again to an evening peak of 2510veh/hour in the 5.30-6.30 hour.

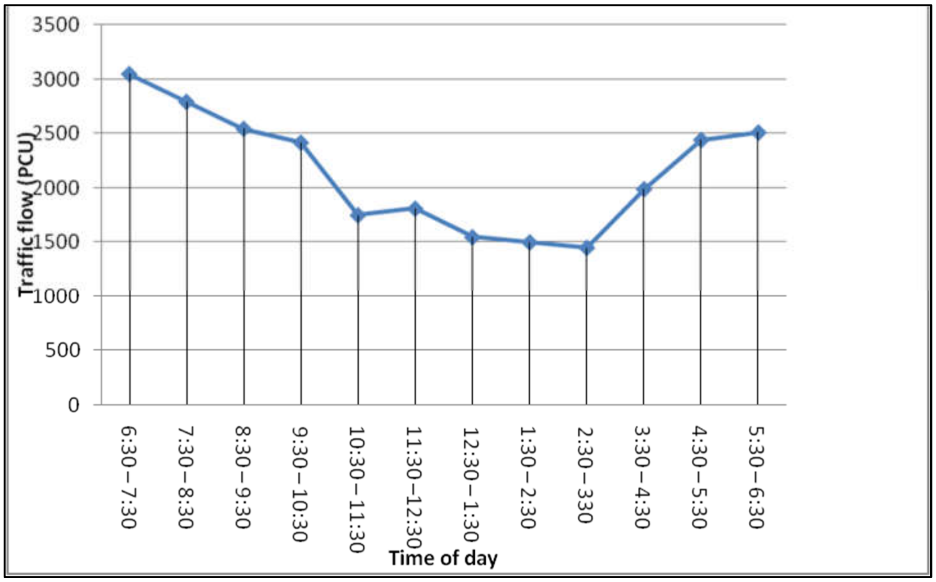


Figure 5.2: Typical daily flow variation along the Githurai-Roysambu segment (2015)

Segment 2 exhibits a morning peak in the 9.30-10.30am hour with 3629veh/per hour. The flow then falls to a low of 2471veh/hr in the 12.30-1.30pm hour before rising again to an evening peak of 3287veh/hour in the 4.30-5.30 hour.

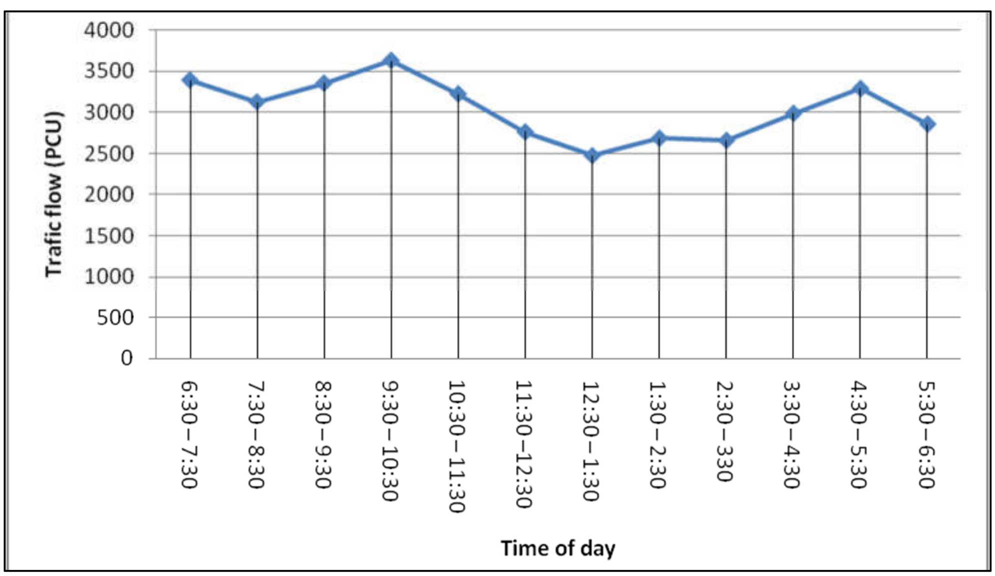


Figure 5.3: Typical daily flow variation along the Roysambu-Ruaraka segment (2015)

Segment 3 exhibits a morning peak in the 7.30-8.30am hour with 4340veh/per hour. The flow then falls to a low of 2731veh/hr in the 3.30-4.30pm hour before rising again to an evening peak of 3482veh/hour in the 5.30-6.30 hour.

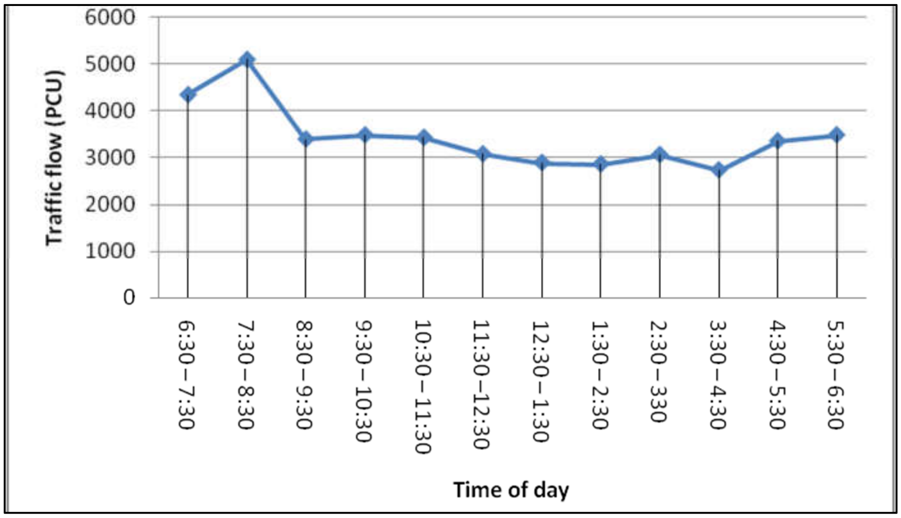


Figure 5.4: Typical daily flow variation along the Ruaraka-Muthaiga segment (2015)

Segment 4 exhibits a morning peak in the 6.30-7.30am hour with 6627veh/per hour. The flow then falls to a low of 3154veh/hr in the 12.30-1.30pm hour before rising again to an evening peak of 4740veh/hour in the 5.30-6.30pm hour.

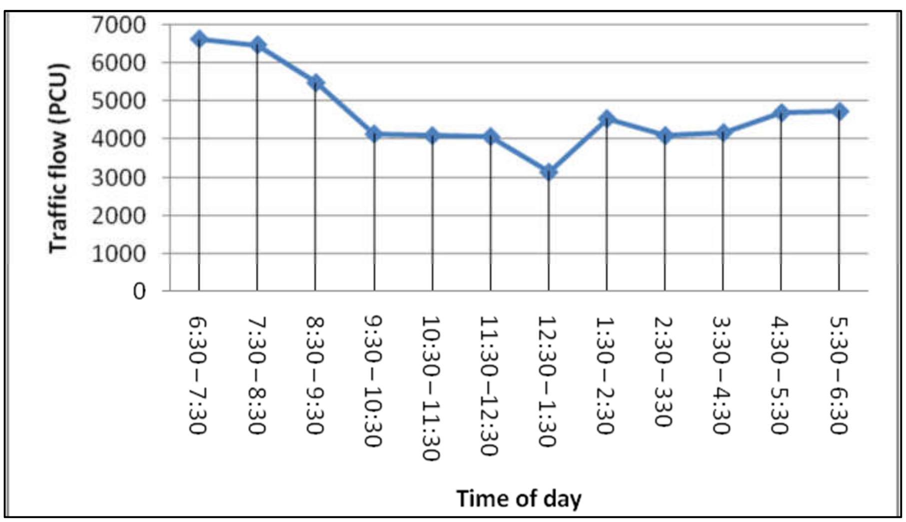


Figure 5.5: Typical daily flow variation along the Muthaiga-Pangani segment (2015)

Table 5.3 below shows the peak flow rate for and the peak-hour factor for the peak hour along each route segment. The peak flow rate was determined by identifying the peak 15-minute volume within the peak hour and then multiplying it by 4. The Peak-Hour Factor was established using the equation

$$PHF = \frac{V}{4*V_{15}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.1$$

Where PHF is the Peak-Hour Factor, V is the hourly volume in the peak hour, and V_{15} is the volume during the peak 15-min of the peak hour.

Table 5.3: Peak flow rates and Peak-Hour Factors along the route segments (2015)

Segment No.	**Description**	**Peak 15-min flowrate (veh/hr)**	**Peak Hour Factor**
1	Githurai - Roysambu	3176	0.96
2	Roysambu - Ruaraka	4272	0.85
3	Ruaraka - Muthaiga	5808	0.88
4	Muthaiga - Pangani	8128	0.88

Segment 4 had the peak flow rate of 8128veh/hr with a PHF of 0.88. The PHF values appear to decrease towards the Nairobi CBD indicating an increasing variation in flow rate towards the city centre.

Figure 5.6 below shows the split between private and public transport vehicles along each segment of the study route. The average share of PCUs is 73:27 for private and public transport vehicles respectively.

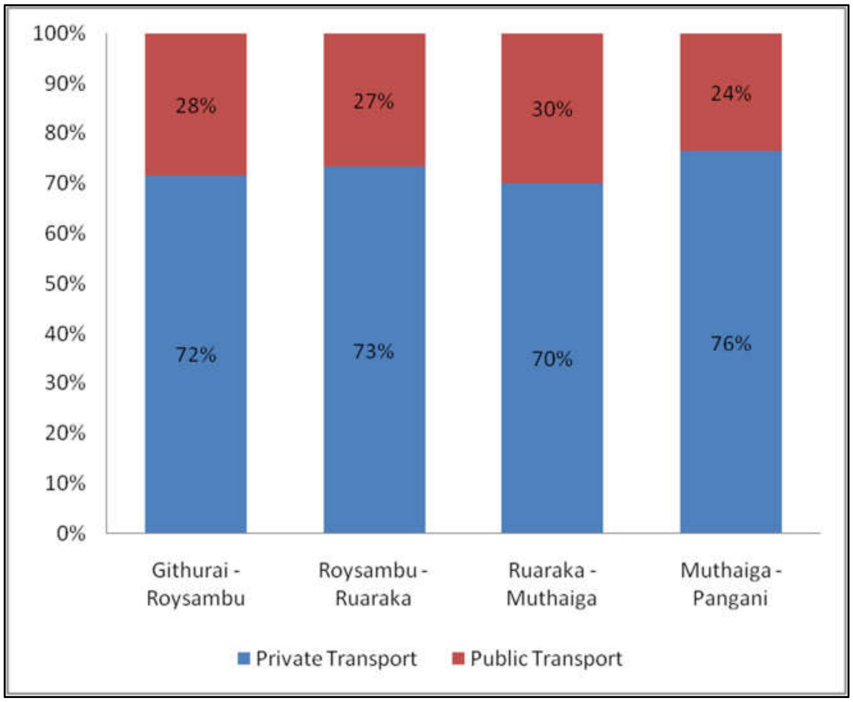


Figure 5.6: Daily traffic volume split between private and public transport in PCUs (2015)

5.2.4 Discussion of the Results

On the Nairobi-Thika Highway, the volume of traffic increases progressively as one moves towards the Nairobi CBD. This is due to the fact that the CBD is the main attraction for trips made in Nairobi. Private vehicles form the bulk of traffic along the Nairobi-Thika Highway constituting an average of 71% of traffic on all route segments while PSVs constitute an average of 23% of the total vehicles. This shows a clear preference for private transport by car owners.

KenHA (2007) carried out comprehensive traffic studies along the Nairobi-Thika Highway in 2007 as part of the feasibility studies for the upgrading of the highway which was completed in 2013. A comparison of their ADT projections for vehicular traffic for the year 2011 with the daily traffic collected in this study shows remarkable variation in the traffic mix since then. Private vehicles constituted about 33% of the traffic mix in contrast to the 73% obtained in this study. This growth is attributable to the traffic induced by the construction of the highway as well as changes in land-use in the areas served by the highway

PSVs constituted about 38% which appear to have reduced to 23% in this study. This might imply that the upgrading of the highway made it more attractive to motorists due to the reduced journey times and the associated reduction in vehicle operating costs. It may also be attributed to general growth in car ownership in Kenya and particularly in Nairobi. Among PSVs in 2011, 14-seater matatus and buses took 84% and 16% respectively while this study shows them taking 33% and 67% respectively. This change shows an increase in the preference for higher occupancy public transport vehicles. The earlier study did not distinguish between buses of different capacities while this study measured 33-seater buses separately from the 51-seater buses. This might explain the variance in the proportions of matatus and buses. The main limitation in this study is that non-vehicular traffic such as motorcycles, bicycles and pedestrians were not considered

5.3 Vehicle Occupancy

Occupancy data collected for goods vehicles was excluded from further analysis since these vehicles are primarily used to transport goods. Data collected for the vehicle occupancy survey was tabulated in 15-minute intervals by first averaging the occupancy values the vehicles sampled in each 15-minute counting period. This was done for each of the four counting stations. The data was then further reduced into one hour intervals by averaging values for hour. Data for the three days was combined by averaging the values for each station. The average occupancy figures for each station were computed for the whole day. These values were compared to those obtained from CES & APEC (2007) where possible. Percentage occupancy rates were also established for each vehicle type.

5.3.1 Average Occupancy

The average occupancy values for the different vehicle types were computed for each counting station by simply averaging the values obtained for each vehicle type in a day.

$$Avg\ occupancy = \sum_{i=1}^{n=12} Occ_i \Big/ n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.2)$$

Where: Occ_i = Average occupancy in the i^{th} hour

The values obtained were tabulated and compared to the values given by CES & APEC (2007) where applicable. They were also compared to the respective seat capacities of the different vehicles

5.3.2 Variation of Occupancy Rates Across the Day

The occupancy values for every hour were presented as percentages of the respective vehicles seat capacities.

$$Occupancy\ rate = Occ_i / Seat\ capacity \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

These values were then plotted on a graph to give the variation of occupancy rates across the day.

5.3.3 Variation of Occupancy Rates Along the Route

The variation of occupancy rates along the route was obtained by plotting the average occupancy rates for the different links against the respective links.

5.3.4 Established Average Occupancy

The hourly-average occupancy values for each vehicle type along each of the four route segments are given in **Appendix D**. A summary of the same is given in

Table 5.4 below. For private cars, an average occupancy of 1.65 persons per car was established with a standard deviation of 0.33. This is against 1.8 persons per car as obtained by CES & APEC (2007). An average of 12.7 persons per vehicle with a standard deviation of 1.98 was established for 14-seater matatus against 13.1 persons per vehicle from the earlier study. An average of 50 persons per vehicle with a standard deviation of 10.12 was obtained for large buses against 37.7 persons per vehicle from the earlier study. Private transport vehicles were noted to have higher deviations in occupancy relative to capacity than the public transport vehicles.

Table 5.4: Summary of the established occupancy values (2015)

	Private Transport			Public Transport			
Link	**Cars**	**33-seater private bus**	**62-seater bus private**	**10-Seater Matatus**	**14-seater matatus**	**33-seater matatu**	**51-seater matatu**
Githurai - Roysambu	1.71	15.66	25.25	8.77	13.02	30.53	43.05
Roysambu - Ruaraka	1.39	17.72	23.99	9.33	12.99	33.47	50.71
Ruaraka - Muthaiga	1.63	17.79	22.88	9.04	12.39	33.93	51.52
Muthaiga - Pangani	1.87	17.85	21.77	7.44	12.39	31.99	54.72
Overall Average	**1.65**	**17.26**	**23.47**	**8.64**	**12.70**	**32.48**	**50.00**
Standard dev	**0.33**	**8.18**	**11.50**	**1.72**	**1.98**	**5.61**	**10.12**
Values CES & APEC (2007)	**1.8**				**13.1**		**37.9**
Seat Capacity	**5**	**30**	**55**	**10**	**14**	**31**	**51**

5.3.5 Established Variation of Occupancy Rates Across the Day

The average percentage occupancy rates obtained for each hour of day were further averaged across the stations to obtain overall average percentage occupancy for each hour. These values were plotted against the time of day as shown in **Figure 5.7**.

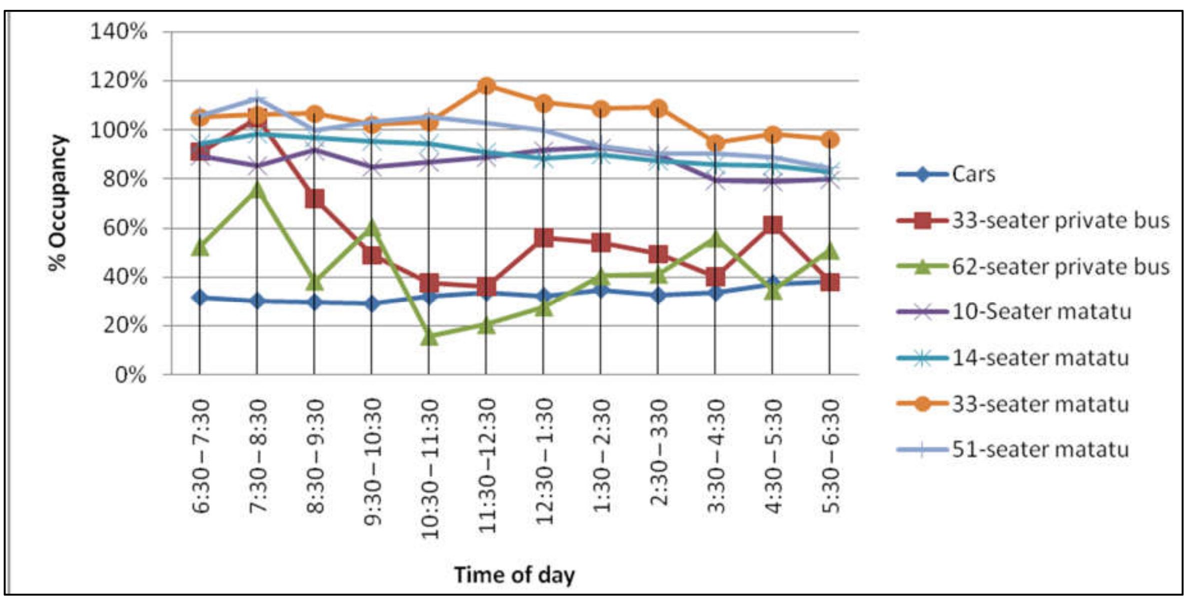
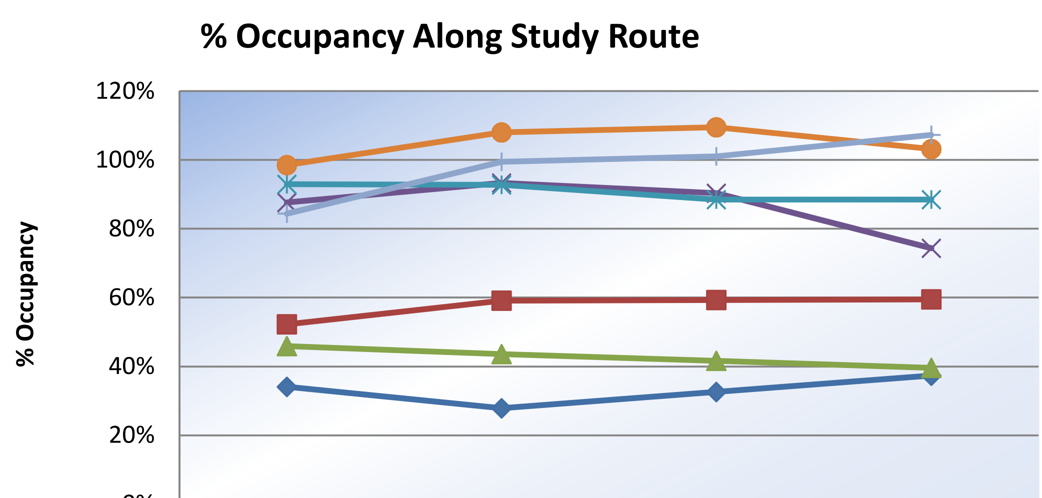


Figure 5.7: Hourly variations of percentage occupancy rates (2015)

Generally, the percentage occupancy rates for all vehicles peaked in the early morning hours up to about 8.30am from whence the occupancy rates would fall gradually; rising again slightly from 11 am; then falling again past 3 pm. The occupancy rates for public transport vehicles were also noted to be much higher than those for private transport vehicles and with smaller relative variations across the day. 33-seater public transport vehicles had the highest occupancy rates with a high of 118% in the 11.30-12.30 hour and a low of 95% in the 3.30 - 4.30 hour. Private cars had the lowest occupancy rates ranging from a high of 38% occupancy in the 5.30-6.30pm hour to a low of 29% in the 9.30 – 10.30am hour. Private buses had the greatest variations in occupancy rates ranging from highs of 76% and 105% to lows of 16% and 36%, for 33-seater and 62-seater private buses respectively.

5.3.6 Established Variation of Occupancy Rates Along the Route

Average occupancy rates for each station were obtained by averaging the values for each station. These values were plotted against the stations as shown in **Figure 5.8**.



	Githurai - Roysambu	Roysambu - Ruaraka	Ruaraka - Muthaiga	Muthaiga - Pangani
Cars	34%	28%	33%	37%
33-seater private bus	52%	59%	59%	60%
62-seater private bus	46%	44%	42%	40%
10-Seater Matatus	88%	93%	90%	74%
14-seater matatus	93%	93%	89%	89%
33-seater Matatu	98%	108%	109%	103%
51-seater Matatu	84%	99%	101%	107%

Figure 5.8: Variation of occupancy rates along the study route (2015)

The 33-seater matatus had the highest occupancy rates along the route with occupancy above 100% along all segments except on the Githurai Roysambu segment; peaking along the Ruaraka-Muthaiga segment with 109% occupancy. This implies an average of 2.79 standees per bus. Occupancy for 51-seater matatus increased progressively from 84% along Githurai-Roysambu segment to 107% on the Muthaiga-Pangani segment. 10 and 14-seater matatus recorded reduced occupancy as they approached Nairobi CBD. Large private buses also gave reduced occupancy as they approached the CBD falling from 46% on the Githurai-Roysambu segment to 40% on the Muthaiga-Pangani segment. Private cars had an occupancy rate of 34% on the Githurai-Roysambu segment; falling to 28% on the Roysambu-Ruaraka segment and then progressively rising to peak at 37% on the Muthaiga-Pangani segment. This implies peak occupancy of 1.85 persons per car.

5.3.7 Discussion of the Results

Average occupancy rates were obtained for cars, matatus, minibuses, and large buses as 1.65, 12.7, 32.5 and 50 persons per vehicle respectively. This was against a seat capacity of 5, 14, 31 and 51 respectively. Expressed as a percentage of the seat capacity, the average occupancy rates were 33%, 91%, 105%, and 98% for cars, matatus, minibuses and large buses respectively. This shows low occupancy rates for private vehicles and high occupancy rates for PSVs.

Another observation was that the occupancy rates for matatus decrease as they approach the Nairobi CBD with 93% occupancy along the Githurai-Roysambu segment falling to 89% along the Muthaiga-Pangani segment. In contrast, the rates for large buses increases from 84% to 107% over the same distance while those for minibuses increase from 98%, to 103% over the same distance. This apparent preference for larger vehicles may be attributed to the increasing ridership towards the Nairobi CBD.

Occupancy rates for all public transport vehicles were found to be higher in the morning hours than in the evening hours while those of private cars remained more or less the same. This shows a higher demand for Nairobi-bound travel in the morning hours than the rest of the day.

Comparison of the occupancy rates obtained in this study with those presented by CES & APEC (2007) show a slight reduction in the occupancy of private cars from 1.9 persons in 2007 to 1.65

in 2015. Occupancy rates for matatus also fell from 13.1 persons in 2007 to 12.7 persons in 2015. This reduction further reinforces the notion of diminishing importance of the 14-seater matatu along the highway. CES & APEC did not distinguish minibuses and large buses hence it was not possible to compare their findings on bus occupancy with data from this study.

Challenges were encountered in the collection of occupancy data using the windshield method due to the high speed of moving vehicles. This was especially so in the case of buses, hence some of the values obtained for these vehicle classes were dependent on human judgment. Another challenge was encountered in the categorization of buses since their capacities varied considerably hence the researcher's experience was used to categorize the buses.

5.4 Computation of Ridership Parameters

This section details the development of common ridership parameters for the Nairobi-Thika Highway. These include passenger loads, passenger load profiles and passenger-kilometres. These parameters were established from the cross-sectional traffic volume and occupancy data discussed in the previous section as proposed by Kadiyali (2002). The results are discussed with respect to the reviewed literature and the objectives of this study.

5.4.1 Passenger Loads and Load Profiles

Passenger loads were computed by multiplying the vehicle counts for each vehicle type by their corresponding occupancy values on a route segment as determined from the occupancy survey. Goods vehicles were excluded from the passenger-load computations. The passenger load carried by mode m over segment i in hour j was given by:

$$P_{mij} = V_{mij} * O_{mij} \;\dots\dots\dots\dots (5.4)$$

Where P_{mij} is the passenger load carried by mode m over route segment i in the j^{th} hour; V_{mij} is the cross-sectional vehicle count for mode m along route segment i in the j^{th} hour; and O_{mij} is the corresponding average occupancy of mode m along route segment i in the j^{th} hour. Various combinations of the resultant passenger loads could be obtained by summing up across a number of hours or across several modes

5.4.2 Established Passenger Loads and Load Profiles

Table 5.5 below gives the hourly passenger loads for each vehicle type across the day along the Muthaiga-Pangani route segment (Segment 4). 7373 passengers travelled by car along Segment 4 between 7.30 and 8.30 am. The row totals in the table give the hourly total passenger loads carried by all the modes considered. For example, 11,489 passengers travelled along route segment 1 on all modes in the hour between 7.30 and 8.30 am. Similarly, the column totals in the table give the daily passenger load carried by an individual mode along segment 4. In this case, 64,830 passengers travelled by car along route segment 4 across the day. The total passenger load for the day along route segment 4 was computed as 290,775 passengers.

Table 5.5: Passenger loads along the Muthaiga-Pangani route segment; Segment 4 (2015)

	Private Transport			Public Transport				
Time of day	Cars	10-14 seater vans	62-seater bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	9,191	1,583	73	111	3,772	7,564	9,218	**31,514**
7:30 – 8:30	7,373	3,377	324	153	6,499	11,412	11,489	**40,627**
8:30 – 9:30	6,273	1,600	75	50	3,815	4,687	11,756	**28,257**
9:30 – 10:30	4,564	608	138	22	4,240	3,510	5,680	**18,762**
10:30 – 11:30	4,075	557	24	47	4,553	4,762	9,239	**23,258**
11:30 –12:30	4,676	376	-	32	3,812	3,700	7,014	**19,609**
12:30 – 1:30	3,445	470	-	77	3,227	3,511	5,233	**15,962**
1:30 – 2:30	4,861	2,293	71	24	3,479	2,679	8,585	**21,992**
2:30 – 330	3,807	1,870	37	16	3,262	2,256	6,472	**17,719**
3:30 – 4:30	4,264	2,637	31	36	3,827	2,311	10,450	**23,556**
4:30 – 5:30	6,407	894	94	53	4,326	5,285	6,055	**23,114**
5:30 – 6:30	5,894	147	129	32	5,055	4,597	10,551	**26,405**
Total	**64,830**	**16,412**	**996**	**653**	**49,868**	**56,275**	**101,742**	**290,775**
	22.30%	5.64%	0.34%	0.22%	17.15%	19.35%	34.99%	**100.00%**

The above tabulation was repeated for all the four route segments considered (**See Appendix E**). The results of passenger loads by vehicle-type was plotted against distance to yield passenger-load profiles as shown in **Figure 5.9** below

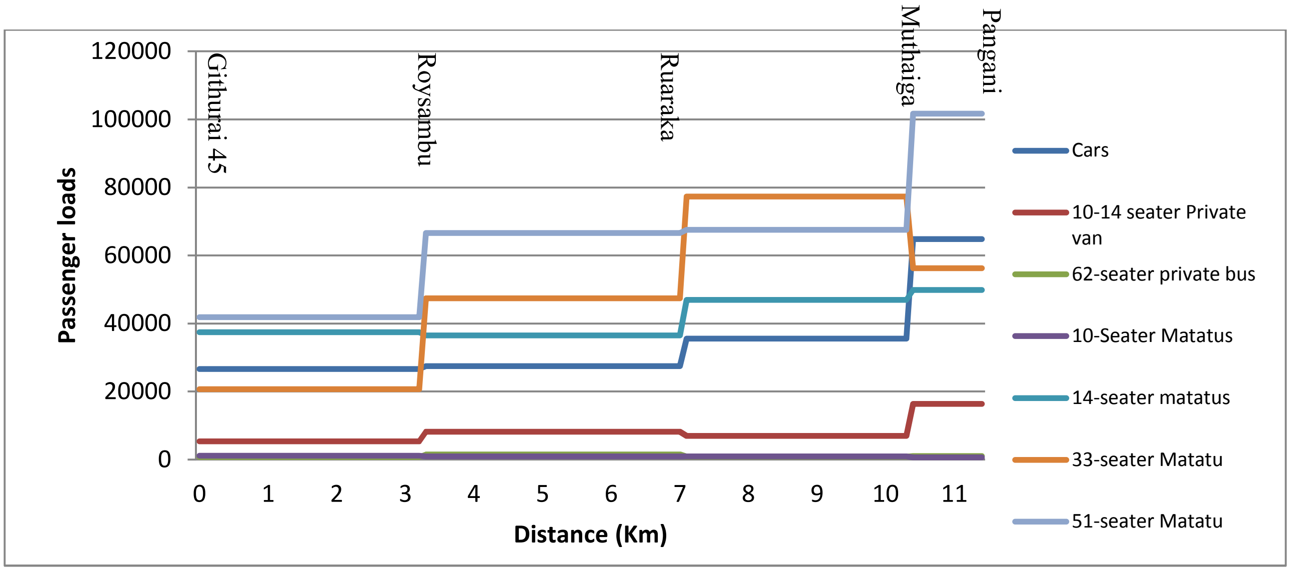


Figure 5.9: Passenger-load by vehicle-type, against distance along the study route (2015)

51-seater public transport buses had the highest passenger loads on all but one route segment between Ruaraka and Muthaiga. 33-seater buses dominated the passenger load along this segment. The combined passenger load along each segment of road was also plotted against distance as shown in **Figure 5.10**.

Figure 5.10: Combined passenger load against distance along the study route (2015)

Source: Author (2017)

The passenger load increases progressively towards Nairobi CBD; with the least passenger load of 133,962 passengers observed along the Githurai-Roysambu route segment; and the biggest passenger load of 290,775 passengers observed along the Muthaiga-Pangani link.

The passenger-load modal split results for the four route segments were plotted on a stacked bar graph as shown in **Figure 5.11** below. These values are as a result of applying Equation 5.8 on each of the four route segments.

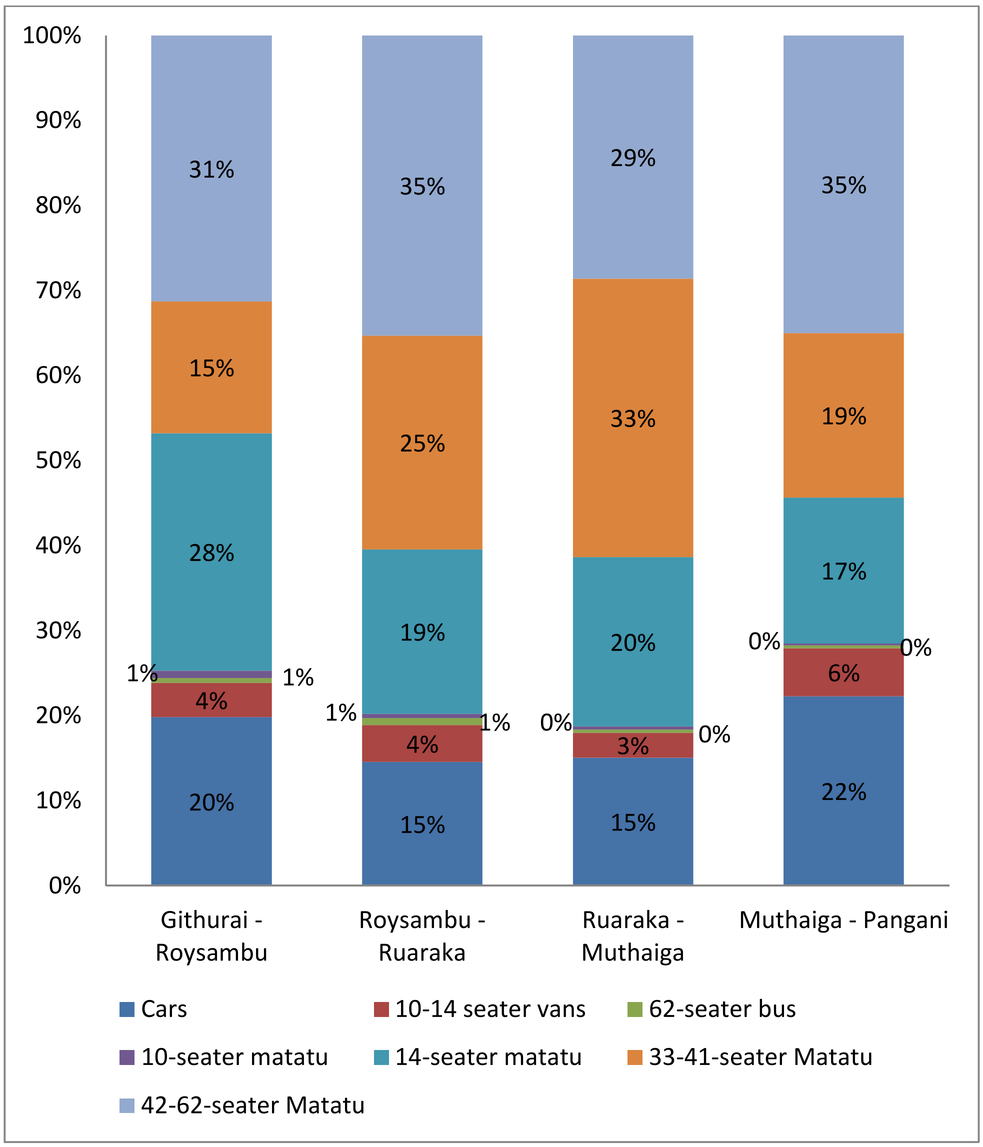


Figure 5.11: Passenger load modal split along the four segments (2015)

Large buses took the largest share of passenger load along all but one segment between Ruaraka and Muthaiga where 33-seater matatus dominate. **Figure 5.12** below shows the passenger load modal split among public transport vehicles. This was done by setting the number of modes, M to four to include only public service vehicles. Large buses dominate the passenger loads followed by 33-seater matatus, 14-seaters and 10-seaters in that order. This is especially apparent along the Muthaiga-Pangani segment where large buses take 49% of the passenger load against 27% by 33-seaters, 24% by 14-seaters and less than 1% by 10-seater matatus.

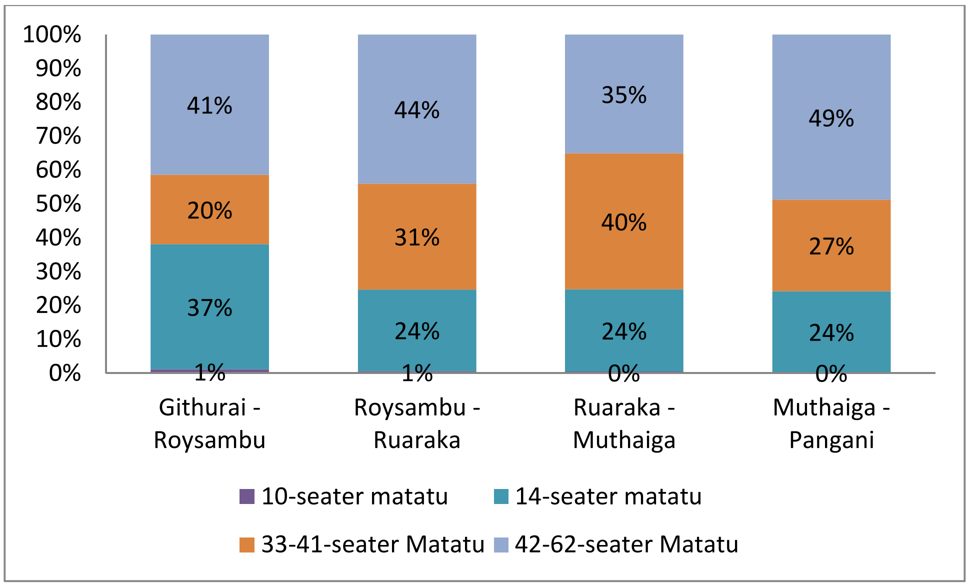


Figure 5.12: Passenger load modal split among public transport vehicles (2015)

Source: Author (2017)

5.4.3 Passenger-km and the Passenger-km Modal Split

From the passenger-load profiles developed above, the passenger-km covered could be obtained as simply the area below the passenger-load profiles. Theoretically, the passenger-kilometres covered by mode m along route segment i in the j^{th} hour was determined by multiplying the passenger load for mode m in hour j by the corresponding length in kilometers, of route segment i.

$$PK_{mij} = P_{mij} * l_i \dots \dots \dots \dots (5.5)$$

Where PK_{mij} is the total passenger kilometers covered by mode m along route segment i in the j^{th} hour; and l_i is the length in kilometers, of route segment i, P_{mij} is the passenger load observed on mode m along segment i in hour j. Just as for passenger loads, different combinations of the passenger kilometres could be obtained by summing up the PK_{mij} across several hours or across several route segments

5.4.4 Established Passenger-km and Pass-km Modal Split

To obtain the percentage share of the passenger-km covered by a particular mode along a route segment in one hour, passenger load observed on each vehicle was multiplied by the number of vehicles of that particular type observed. **Table 5.6** below gives the hourly passenger-km values for each vehicle type along the Githurai-Roysambu route segment (Segment 1).

Table 5.6: Passenger-km values along the Githurai-Roysambu route segment; Segment 1 (2015)

	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	**10-14 seater Private van**	**62-seater private bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 7:30	11120	980	94	367	12210	6788	15258	46816.796
7:30 – 8:30	7545	2506	309	468	11944	6135	15739	44645.998
8:30 – 9:30	7058	1316	0	342	12184	6720	13673	41292.202
9:30 – 10:30	7062	2537	0	345	9675	7687	13643	40949.294
10:30 – 11:30	5784	1251	0	358	8362	7424	13026	36205.737
11:30 –12:30	6171	616	0	244	9185	7145	11176	34538.03
12:30 – 1:30	4308	2694	163	426	8666	4238	8565	29060.279
1:30 – 2:30	5098	721	75	192	9121	4467	8533	28206.718
2:30 – 330	4820	840	0	337	9546	3329	8462	27333.013
3:30 – 4:30	6756	1008	1279	297	8756	2823	9937	30856.779
4:30 – 5:30	9980	1424	407	210	9005	4784	8417	34226.557
5:30 – 6:30	9408	1306	57	109	11160	4823	7685	34548.24
	85109	17199	2383	3695	119815	66363	134115	428679.64

Source: Author (2017)

3.2 kilometres. 11,120 pass-km were covered by car along Link 1 between 7.30 and 8.30 am. The row totals in the table give the hourly total passenger –km covered by all the modes considered. For example, 46,816 pass-km was covered along route segment 1 on all modes in the hour between 6.30 and 7.30 am. Similarly, the column totals in the table give the daily passenger-km covered by an individual mode along route segment 1. In this case, 85,109 pass-km were covered by car along route segment 1 across the day. The above process was repeated for all the four route segments considered (**See Appendix F**).

A summary of the total passenger-kilometres covered in each vehicle type along each route segment through the day is given in **Table 5.7** below.

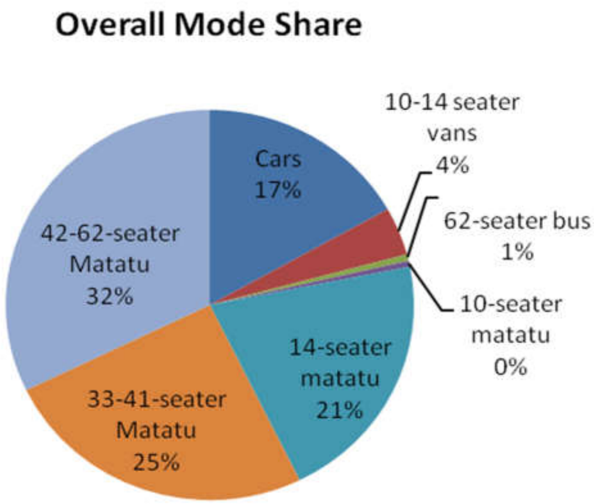
Table 5.7: Daily Passenger-km values along the study route (2015)

	Private Vehicles			Public Transport Vehicles				
Route Segment	**Cars**	**10-14 seater vans**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater Matatu**	**42-62-seater Matatu**	**Total**	**Distance (km)**
Githurai - Roysambu	85,109	17,199	2,383	3,695	119,815	66,363	134,115	428,680	**3.2**
Roysambu - Ruaraka	104,486	31,142	5,818	3,599	138,814	180,192	253,272	717,322	**3.8**
Ruaraka - Muthaiga	117,441	23,009	2,819	3,035	154,949	255,266	222,940	779,460	**3.3**
Muthaiga - Pangani	71,313	18,053	1,095	718	54,855	61,902	111,917	319,853	**1.1**
Total	**378,349**	**89,402**	**12,116**	**11,048**	**468,433**	**563,723**	**722,243**	**2,245,315**	**11.4**

Source: Author (2017)

134,115 pass-km were covered in 42-62-seater matatus along route segment 1. 428,680 pass-km were covered by all modes along route segment 1 through the day. 722,243 pass-km were covered by 42-62-seater matatus along the entire route in a day. The total passenger-km covered by all modes along the entire route length through the day; in this case 2,245,315 pass-km.

The mode shares of the pass-km were plotted in the pie charts in **Figure 5.13** below. The overall mode share graph considers all modes while the PSV mode share considers only public transport vehicles



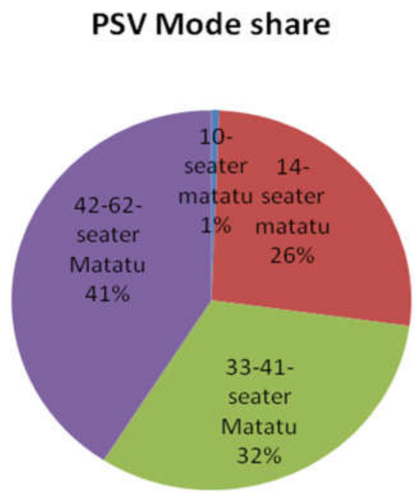


Figure 5.13: Overall modal split and transit modal split

Source: Author (2017)

Private cars covered 16.85% of the passenger-kilometres, large transit buses, labeled as 42-62 seater matatu, covered 32.17% of the passenger-kilometres, while 14-seater matatus covered 20.86% of the passenger-km. Private and public transport vehicles covered 21.4% and 78.6% of the passenger-km respectively. Among PSVs, large buses dominated with 41% of the transit passenger-km, followed by 33-seater buses with 32%, 14-seater matatus with 26%, and 10-seater matatus with less than 1% of the transit passenger-km.

5.5 Vehicle Speeds

5.5.1 Spot Speeds

The spot speed of each sampled vehicle as it traversed the 50m road section was computed in kilometers per hour as follows:

$$v_i = \frac{D}{t_i} * 3.6 \ldots\ldots\ldots\ldots (5.6)$$

Where v_i is the spot speed of vehicle i in km/h, D is the distance covered by the vehicle in metres - in this case 50m, and t_i is the time, in seconds, taken by vehicle i to cover distance D.

5.5.2 Time Mean Speed

This is the arithmetic average of speeds of vehicles observed passing a point on a highway. It was computed from the spot speeds as follows:

$$v_t = \frac{1}{n}\sum_{i=1}^{n} v_i \text{.................. (5.7)}$$

Where v_t is the time mean speed of all vehicles sampled, n is the number of observations, and v_i is the spot speed of the ith vehicle

5.5.3 Space Mean Speed

This is a statistical term denoting the average speed based on the average travel times of vehicles to traverse a section of a roadway. It averages the spot speeds but spatial weightage is given instead of temporal. It was computed as follows:

$$v_s = \frac{n}{\sum_{i=1}^{n}\frac{1}{v_i}} \text{ ………………………… (5.8)}$$

5.5.4 Established Speeds

The spot speeds obtained for each sampled vehicle (**See Appendix H**) were grouped into a frequency distribution table, Table 5.8. Passenger cars had the widest range of speeds with a range of 107km/h while 26-seaters had the smallest range of speeds at 18.5km/h. Time mean speeds and space mean speeds were determined for each vehicle category, and are given in the same table

Table 5.8: Frequency distribution of spot speeds (2015)

Speed (km/h)		Frequency						
Labels	Midpoints	Passenger Cars	10-seaters	14-seaters	26-seaters	33-seaters	51-seaters	62-seaters
25.0- 29.9	**27.45**	1	0	0	0	0	0	0
30.0- 34.9	**32.45**	0	0	0	0	0	0	0
35.0- 39.9	**37.45**	0	0	0	0	0	0	0
40.0- 44.9	**42.45**	0	0	0	0	0	0	0
45.0- 49.9	**47.45**	0	0	0	0	0	0	0
50.0- 54.9	**52.45**	2	0	0	0	2	0	0
55.0- 59.9	**57.45**	1	1	1	0	2	0	1
60.0- 64.9	**62.45**	3	5	4	1	8	6	2
65.0- 69.9	**67.45**	2	4	1	0	6	7	1
70.0- 74.9	**72.45**	9	1	5	1	8	16	1
75.0- 79.9	**77.45**	9	4	14	4	2	6	0
80.0- 84.9	**82.45**	11	4	5	0	2	5	1
85.0- 89.9	**87.45**	17	4	4	0	2	4	0
90.0- 94.9	**92.45**	19	1	5	0	1	2	0
95.0- 99.9	**97.45**	7	1	1	0	0	2	0
100.0- 104.9	**102.45**	3	1	1	0	0	0	0
105.0- 109.9	**107.45**	5	0	0	0	0	1	1
110.0- 114.9	**112.45**	0	0	1	0	0	0	0
115.0- 119.9	**117.45**	0	0	0	0	0	0	0
120.0- 124.9	**122.45**	4	0	0	0	0	0	0
125.0- 129.9	**127.45**	1	0	0	0	1	0	0
130.0- 134.9	**132.45**	1	0	0	0	0	0	0
135.0- 139.9	**137.45**	1	0	0	0	0	0	0
Time mean speed		86.9	75.5	79.0	73.4	70.2	74.6	71.9
Space mean speed		82.9	73.5	77.4	72.8	68.2	73.4	69.0
Standard deviation		16.9	12.6	11.2	7.0	13.7	10.4	17.3
Max		134.3	101.1	109.1	78.6	125.0	105.9	105.9
Min		27.3	55.4	57.5	60.2	51.6	59.0	55.4
Range		107.1	45.7	51.6	18.4	73.4	46.9	50.5

Figure 5.14 below shows the space mean speeds of different modes. Passenger cars had the highest speed with an average of 82.9km/h, 14-seater matatus followed with 77.4km/h, 10-seater matatus with 73.5km/h, 51-seater buses with 73.4km/hr, 26-seater minibuses with 72.8km/h, 62-seater buses with 69km/hr, and 33-seater buses with 68.2km/h.

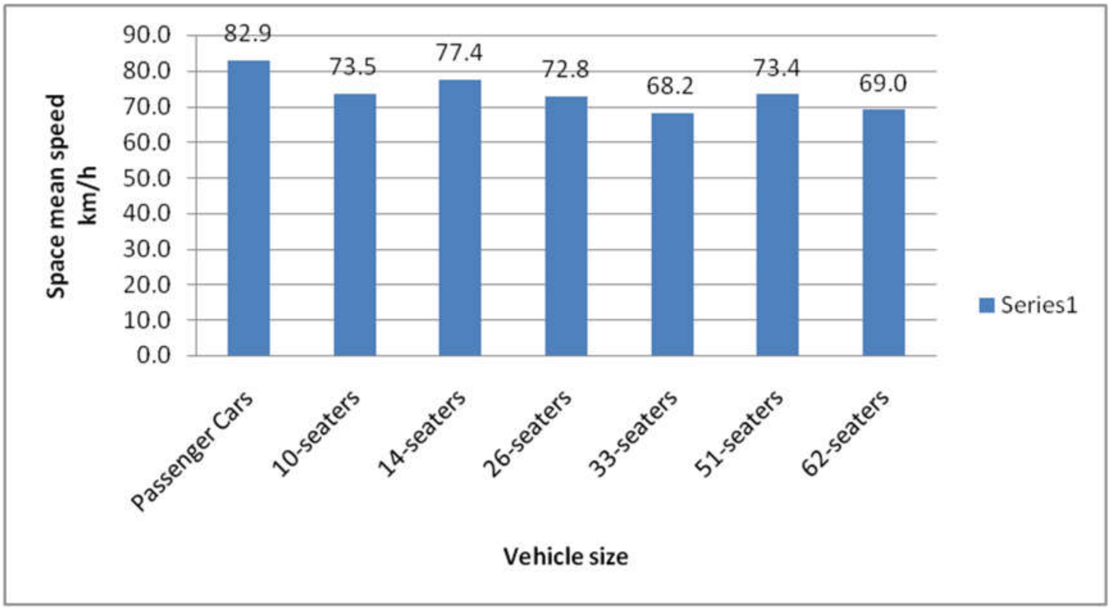


Figure 5.14: Space mean speed across different modes (2015)

The posted speed limit along the section is 100km/hr, hence, the average speeds of all vehicle types were well below the speed limit. About 15.6% of passenger cars and 4.8% of 14-seater matatus were in violation of the posted speed limit. The general trend indicated little reduction in speed with increase in vehicle size.

5.6 Vehicle Plinth Area

5.6.1 Average Area of Vehicles

The 15-minute traffic count of different sizes of passenger cars was tabulated and used to determine the proportions of different car sizes on the road. The dimensions of the representative car make, and thus the area, were tabulated alongside the respective car size car size. The proportions of different car sizes were used to compute the weighted average plan area of a passenger car as follows:

$$A_p = \frac{1}{n}\sum_{i=1}^{n} A_r \ldots\ldots\ldots\ldots (5.9)$$

Where A_p is the average projected area of a passenger car, n is the number of passenger car categories considered (six categories), and A_r is the area of the representative model in each size category.

The dimensions of the representative van or bus make were tabulated alongside their respective projected areas, and thus the area, were tabulated alongside the respective car size car size. The areas per passenger were computed by dividing the area of each vehicle sized by the number of seats in such a vehicle. A comparison was made of the seat capacities of the buses in practice against the capacities as per the Kenya Bureau of Standards (DKS 372: 2018).

5.6.2 Established Projected Plan Areas of Vehicles

The volumes of different types of passenger cars observed during the 15-minute count are shown in Table 5.9 below. Saloon cars were the most common, consisting of 54% of all passenger cars while double cab pickups were the least common, representing 6% of passenger cars.

Table 5.9: 15-minute volumes of different passenger car types

Car Sizes	Subcompact car	Saloon	Hatchback	SUV	Double cab pickup	Total
Count	55	208	69	27	24	383
Relative proportions	14%	54%	18%	7%	6%	100%

Table 5.10 below gives the dimensions and resultant areas of select passenger cars and vans. For passenger cars, a weighted average of the areas was computed using the proportions obtained in **Table 5.9** above. The overall average area for passenger cars was obtained as 7.74 square metres. This was taken as the average area of a passenger car in all subsequent computations. The areas of 10 and 14-seater vans were obtained as 7.52m^2 and 7.96m^2 respectively.

Table 5.10: Dimensions of passenger cars and vans common in Kenya

Vehicle Sizes	Representative Make	Length (m)	Width (m)	Area (m^2)	Relative Proportions	Average Area (m^2)
Subcompact car	Toyota Vitz	3.945	1.695	6.69	0.14	7.74
Saloon	Toyota Allion	4.565	1.695	7.74	0.54	
Hatchback	Toyota Fielder	4.400	1.695	7.46	0.18	
SUV	Toyota Harrier	4.720	1.835	8.66	0.07	
Double cab pickup	Toyota Hilux	5.330	1.855	9.89	0.06	
10-seater Matatu	Toyota Townace	4.435	1.695	7.52		7.52
14-seater Matatu	Toyota Hiace	4.695	1.695	7.96		7.96

Source: http://www.automobiledimension.com/ (2017)

Table 5.11 below shows the dimensions and resultant areas of different buses common in Kenya. The smallest minibus has an area of 14.06m^2 while the largest bus has an area of 29.29m^2. Also shown are the maximum seat capacities if the same buses were fitted with seats according to KEBS DKS 372: 2018. Only the 26-seater and 62-seater buses have exceeded the specified capacity by 1 and 2 seats respectively.

Table 5.11: Dimensions of common buses in Kenya

Bus Sizes	Representative Make	Length (m)	Width (m)	Area (m^2)	Capacity to DKS 378: 2018
26-seater	Isuzu NKR	6.391	2.200	14.06	25
29-seater	Isuzu NPR	7.189	2.200	15.82	29
33-seater	Isuzu NQR	7.765	2.200	17.08	33
51-seater	Isuzu FRR	9.220	2.495	23.00	51
62-seater	Isuzu MV	11.180	2.620	29.29	59

Source: Banbros Kenya Ltd (2017)

Figure 5.15 below shows the relationship between the area per sitting passenger and the sitting passenger capacity of the vehicle. The above data shows that in Kenya, passenger cars have the greatest area per seat at 1.55m^2. 51-seater buses take the least passenger sitting space at 0.45m^2 per seat, followed by 62-seater buses at 0.47m^2 per seat. This can be attributed to the fact that 62-seater buses are usually used for long distance travel and hence, more passenger space is provided. 26-seater minibuses also leave less room per passenger (0.54m^2) than 29-seater minibuses (0.55). However, the general trend is as expected whereby the area taken up by a seat varies inversely with the vehicle size.

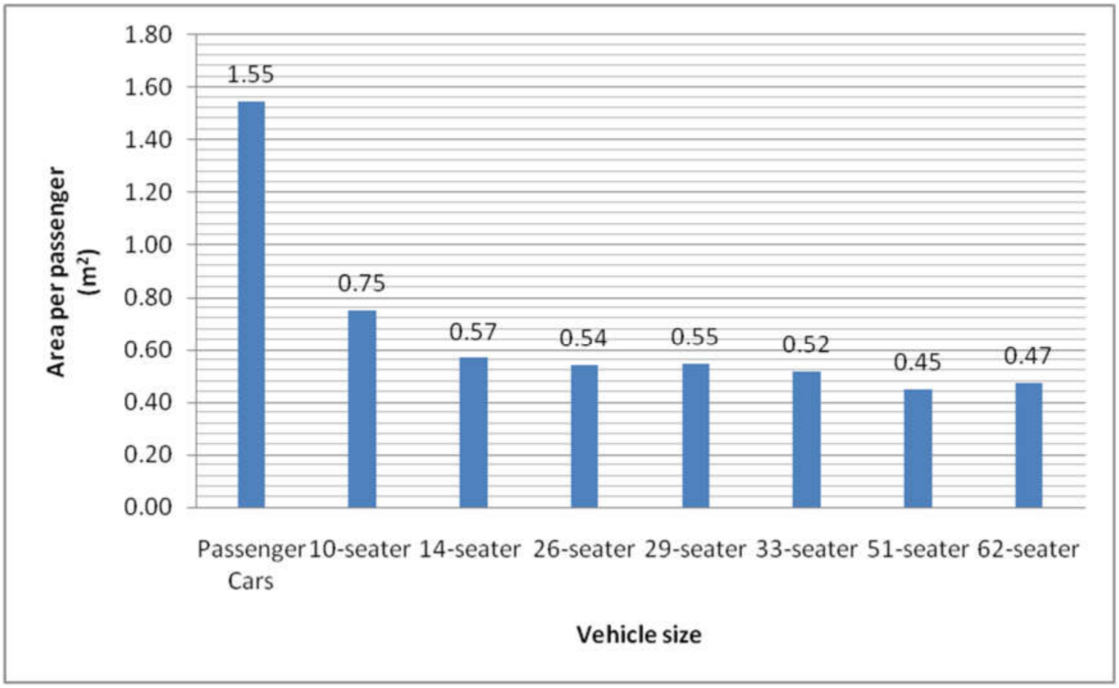


Figure 5.15: Area per sitting passenger vs sitting passenger capacity

5.7 Bus Classification and Capacities According to KEBS Standards (DKS 372: 2018)

Bus specifications given by the Kenya Bureau of Standards were used to develop bus seat layouts for the largest bus in each class (I-V) excluding double-decker buses (Class VI). The layouts were then used to determine the number of passenger seats that can be accommodated in each bus within the standards. The relevant design data and resulting seat capacities are given in **Table 5.12** below. It should be noted that the buses considered here are at the upper limit bus lengths for each class. The maximum capacity for each class is given. The maximum sitting capacity for a single coach bus is thus 69 seats, 104 seats for a single-articulated bus, and 150 seats for a bi-articulated bus. A Midi Bus (Class III) has the highest space utilization at $0.38m^2$ per sitting passenger followed by Large Buses (Class IV) at $0.45m^2$. A Mini Bus (Class II) has the lowest space utilization at $0.533m^2$ per passenger, followed by a Micro Bus (Class I) at $0.531m^2$.

Table 5.12: Maximum seat capacities for Bus Classes I-V as per KEBS DKS 372: 2018

Vehicle Class	**Description**	**Max length (m)**	**Max Width (m)**	**Area (m^2)**	**Min Seat Width (m)**	**Min Row Spacing (m)**	**Min Gangway Width (m)**	**Min Door Width (m)**	**Min No. of Doors**	**Max. Seat Capacity**	**Area per passenger (m^2)**
I	Micro Bus	7	2.2	15.4	0.4	0.75	0.3	0.6	1	**29**	0.53
II	Mini Bus	8	2.2	17.6	0.4	0.75	0.3	0.6	1	**33**	0.53
III	Midi Bus	10.5	2.2	23.1	0.4	0.75	0.35	0.6	1	**61**	0.38
IV	Large Bus	12.5	2.495	31.2	0.4	0.75	0.45	1.2	1	**69**	0.45
V (1)	Single-articulated Bus	18	2.65	47.7	0.4	0.75	0.45	1.2	2	**104**	0.46
V (2)	Bi-articulated Bus	26	2.65	68.9	0.4	0.75	0.45	1.2	3	**150**	0.46

CHAPTER 6. **MODEL CALIBRATION AND APPLICATION**

6.1 Introduction

In this chapter, the data analyzed in Chapter 5 is used to calibrate the transit vehicle size optimization model. The model is then applied to select the optimum vehicle size along the Nairobi-Highway

6.2 Relationship between Vehicle Size and Occupancy Rates

The relationship between vehicle size and occupancy rate was determined for the max load hour along each route segment. This was achieved by drawing a scatter plot of vehicle size against occupancy rate for the max load hour. A line or curve of best fit was fitted to the data for each graph and a model governing the relationship between the two variables generated for each case. The model could then be used to interpolate occupancy rates for any size of vehicle.

6.3 Relationship between Vehicle Size and PCE Values

Passenger Car Equivalence vales for different vehicle types were computed using Chandra and Sikdar's (2000) method discussed in Chapter 2 , section 2.41 as follows:

$$PCE_i = \frac{V_c/V_i}{A_c/A_i} \text{.........................} 6.1$$

where V_c and V_i are mean speeds of car and vehicle of type i respectively and A_c and A_i are their respective projected rectangular area (length * width) on the road. The relationship between the PCE values and vehicle size was then established by plotting vehicle size against PCE values. A line of best fit was fitted to the data and a model governing the relationship between the two variables was generated. The model could then used to interpolate PCE values for any vehicle size.

6.4 Vehicle Flows Simulation for Peak Demand

The equation below (See Section 3) was used to generate resultant flows for a range of vehicle sizes with capacity ranging from 5 seats to 100 seats, for peak demand along each route segment.

$$Min\ F_j = \frac{\bar{P}_{mj} * E_z}{\gamma_{zj}.Z} \quad \dots\dots\dots\dots\dots.(6.2)$$

s.t.

$$\gamma_{min} \leq \gamma_{zj} \leq \gamma_{max}$$

$$Z \leq Z_{k\ max}$$

Where F_j is the resultant flow of vehicles in hour j, in Passenger Car Units, and E_z is the Passenger Car Equivalence of vehicle size Z. γ_{min} and γ_{max} are the lower and upper bounds for the average occupancy rate. $Z_{k\ max}$ is the maximum capacity for a vehicle of a particular class. The proposed method is thus a minimization model of Equation 6.2 above subject to the limits of occupancy rates. From this data, flow was plotted against vehicle size for a range of vehicle sizes. . A line of best fit was fitted to the data and a model governing the relationship between the two variables was generated.

This model equation can be used to deduce the vehicle flow that would result from the selection of any vehicle size. A suitable transit vehicle size can then be selected form the equation.

6.5 Established Relationship between Vehicle Size and Occupancy Rates

Figure 6.1 to **Figure 6.4** below show the relationship between occupancy rate and vehicle size along each of the four route segments. A line of best fit is shown on each graph. The type of trend line was selected to ensure the R^2 value of the resulting trend line was above 0.5. For segments 1 and 2, polynomial curves were fitted with squared Pearson correlation coefficients of 0.612 and 0.674 respectively (see **Figure 6.1** and **Figure 6.2**). This implies a moderate correlation between the two variables. The arithmetic equation for the modeled values is shown on each graph.

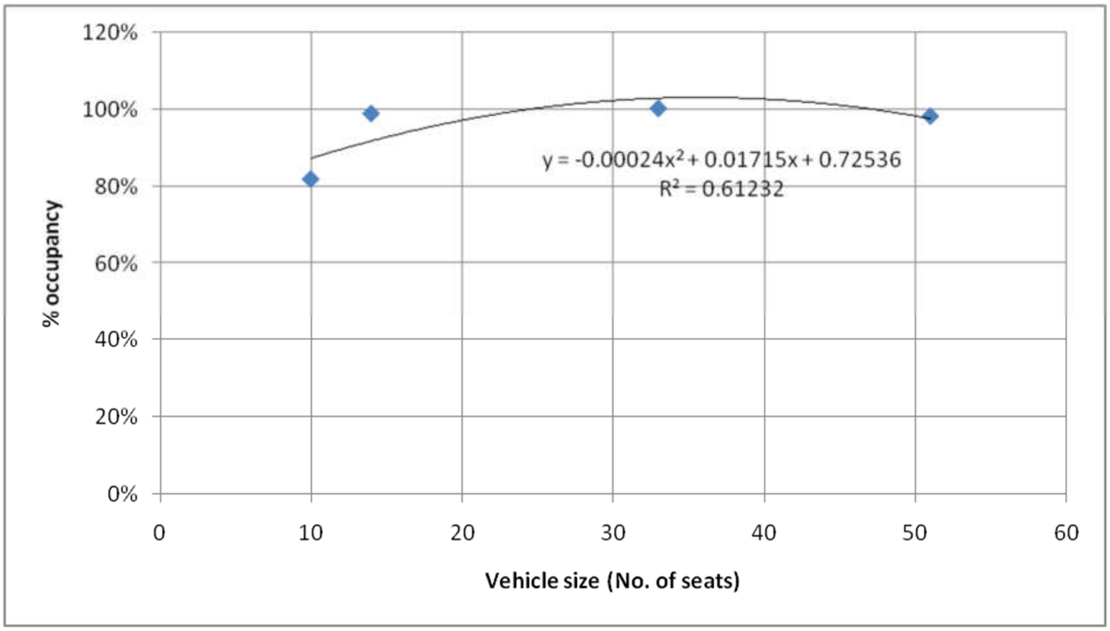


Figure 6.1: % occupancy vs vehicle size along segment 1

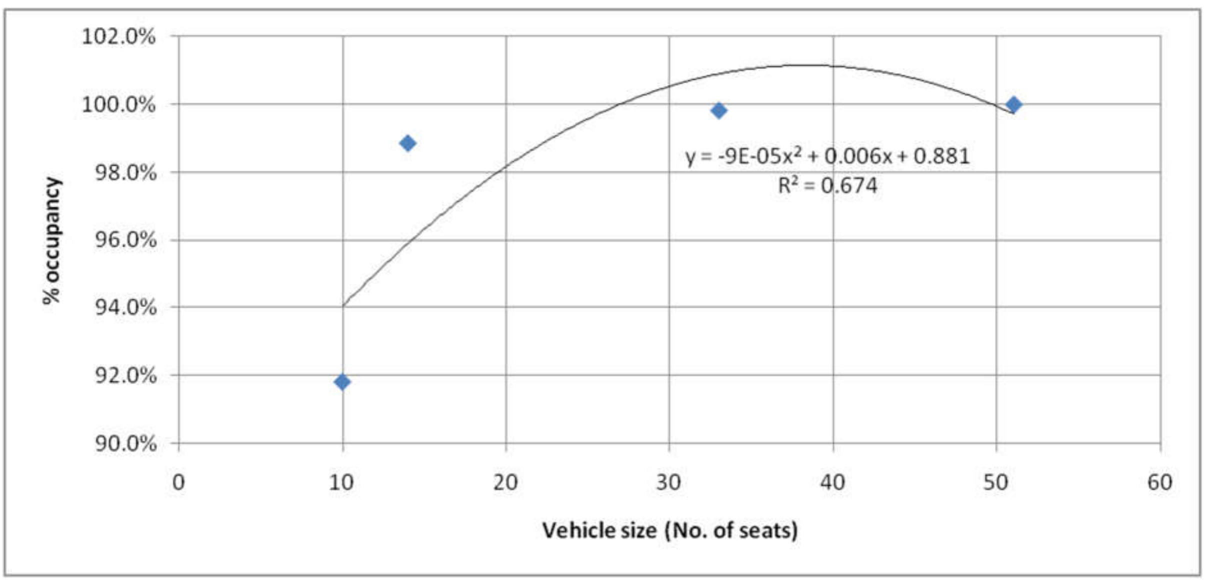


Figure 6.2: % occupancy vs vehicle size along segment 2

For segments 3 and 4, linear trend lines were fitted with squared Pearson correlation coefficients of 0.982 and 0.839 respectively (**Figure 6.3** and **Figure 6.4**). This implies a strong correlation between the two variables. The arithmetic equation for the modeled values is shown on each graph.

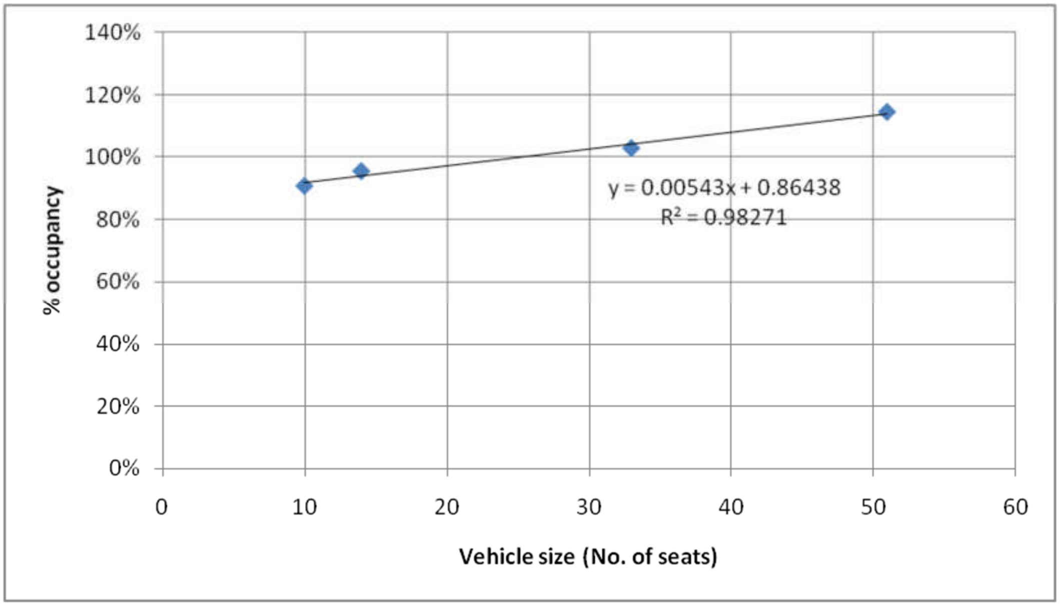


Figure 6.3: % occupancy vs vehicle size along segment 3

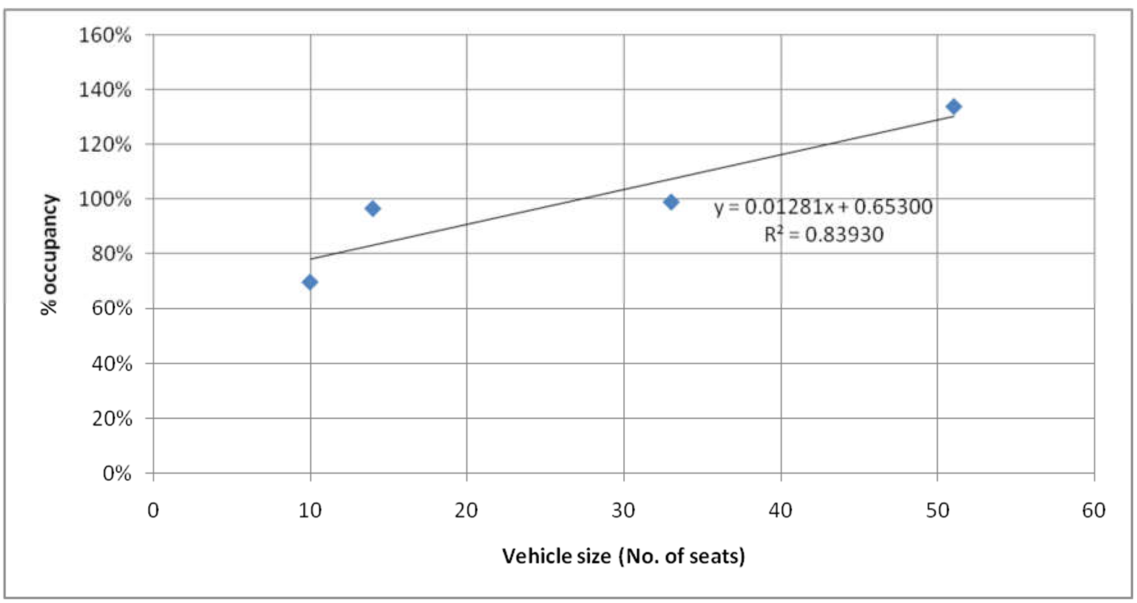


Figure 6.4: % occupancy vs vehicle size along segment 4

6.6 Established Relationship between Vehicle Size and PCE Values

Table 6.1 below shows the observed PCE values for different vehicle sizes measured on level terrain. The values were obtained by applying equation 6.1 to speed and area data. PCE values range from 1.0 for passenger cars to 4.5 for 62-seater buses. These values compare well with the traditional PCE values discussed in Chapter 2, Section 2.4.1.

Table 6.1: Observed PCE values for different vehicle sizes

Vehicle description	Area (m^2)	Number of seats (Z)	Area per seat (m^2)	Speed (Km/h)	PCE (E_z)
Passenger Cars	7.7	5	1.547235	82.9	1.0
10-seater	7.5	10	0.7517325	73.5	1.1
14-seater	8.0	14	0.56843036	77.4	1.1
26-seater	14.1	26	0.54077692	72.8	2.1
33-seater	17.1	33	0.51766667	68.2	2.7
51-seater	23.0	51	0.45105686	73.4	3.4
62-seater	29.3	62	0.47244516	69.2	4.5

Figure 6.5 below shows a plot of PCE values against vehicle size. A line of best fit was added and an equation for the modeled values is shown on the graph. An R^2 value was obtained for the trend line indicating a strong correlation between the two variables. From the equation generated, a PCE value could be computed for any vehicle size.

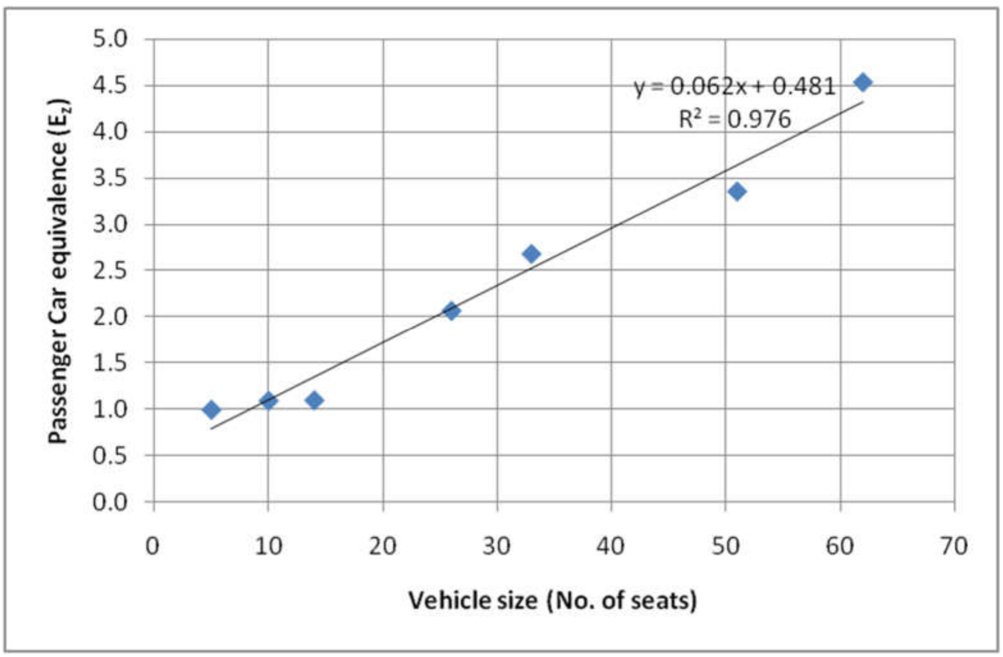


Figure 6.5: Passenger Car Equivalence vs vehicle size

6.7 Established Vehicle Flows for Peak Demand

Table 6.1 below shows the peak demand values for each route segment. It also gives the equations used to compute occupancy, γ_Z, and PCE values, E_Z along each route segment (See Section 6.4 to 6.6). These equations were generated in the previous section. Vehicle size values were generated as integers between 10 and 150. Thus, occupancy rate and PCE value could be computed for each vehicle size between 10 and 150 seats.

Table 6.2: Peak demand values and equations used to model occupancy and PCE values

Segment	Description	Peak Demand	ɣ vs Z	E vs Z
1	Githurai - Roysambu	10819	$y = -0.00024x^2 + 0.01715x + 0.72536$	$y = 0.062x + 0.481$
2	Roysambu - Ruaraka	20329	$y = -0.00009x^2 + 0.00679x + 0.88138$	$y = 0.062x + 0.481$
3	Ruaraka - Muthaiga	34427	$y = 0.00543x + 0.86438$	$y = 0.062x + 0.481$
4	Muthaiga - Pangani	40627	$y = 0.01281x + 0.65300$	$y = 0.062x + 0.481$

For each section, the resultant flows in PCU/h were computed for each vehicle size in terms of number of seats, by applying equation 6.2. **Figure 6.6** and **Figure 6.7** below are plots showing the relationship between vehicle size and the resultant traffic flow, in PCU/h for segments 1 and 2. The type of trend line was selected to ensure the R^2 value of the resulting trend line was above 0.5. A line of best fit is shown on each graph .Second order polynomial curves were fitted with squared Pearson correlation coefficients of 0.944 and 0.924 respectively (see **Figure 6.6** and **Figure 6.7**). The arithmetic equation for the modeled values is shown on each graph.

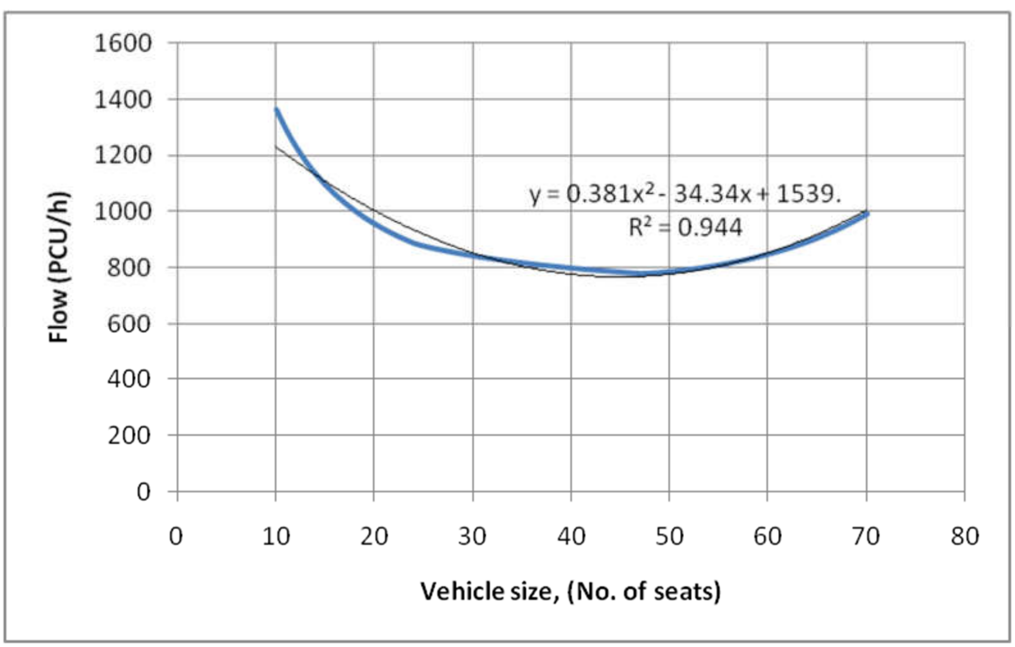


Figure 6.6: Segment 1 flow vs vehicle size

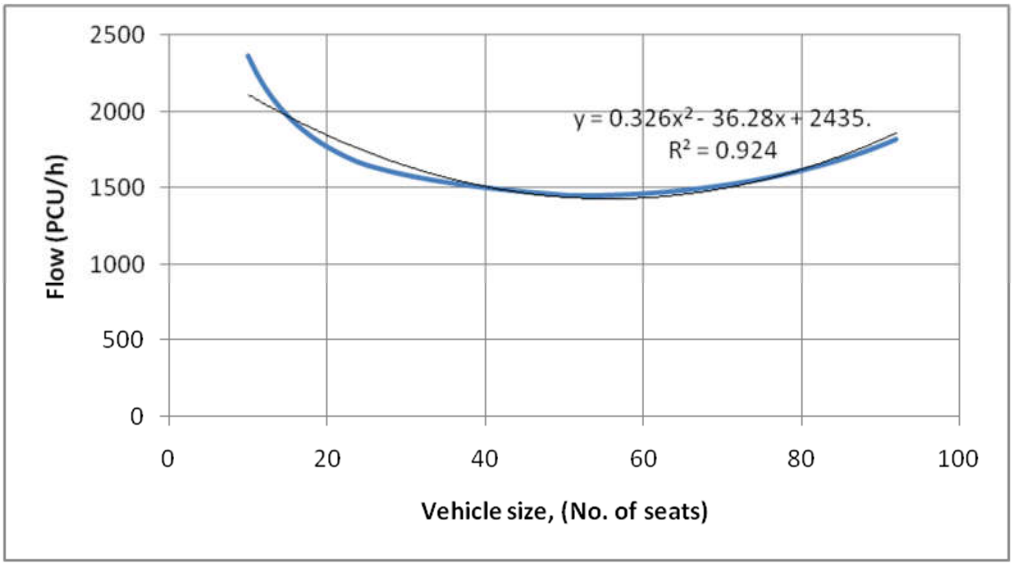


Figure 6.7: Segment 2 flow vs vehicle size

For segments 1 and 2, optimum values for transit vehicle size could be obtained by equating the first derivative of the vehicle size-flow equation to zero. **Table 6.3** below shows the peak demand, first derivative of the vehicle size-flow equations, the optimum vehicle sizes and the resultant vehicle flows for segments 1 and 2. An optimum vehicle size of 45 seats was obtained for the segment 1, resulting in a vehicle flow of 1478PCU; while an optimum vehicle size of 56 seats was obtained for Segment 2, resulting in a vehicle flow of 1455PCU.

Table 6.3: Optimum transit vehicle sizes for segments 1 and 2

Segment	Description	Peak Demand	dy/dx	Optimum vehicle size (Number of seats)	Flow (PCU/h)
1	Githurai - Roysambu	10819	y' = 0.762x - 34.34	45	1478
2	Roysambu - Ruaraka	20329	y' = 0.652x - 36.28	56	1455

Figure 6.8 and **Figure 6.9** below are plots showing the relationship between vehicle size and the resultant traffic flow, in PCU/h for segments 3 and 4. In this case, the resultant vehicle flow varies inversely with the vehicle size. The graph approaches the x-axis asymptotically as the vehicle capacity increases. Thus the optimum vehicle size could not be obtained through a minimization function for these two segments.

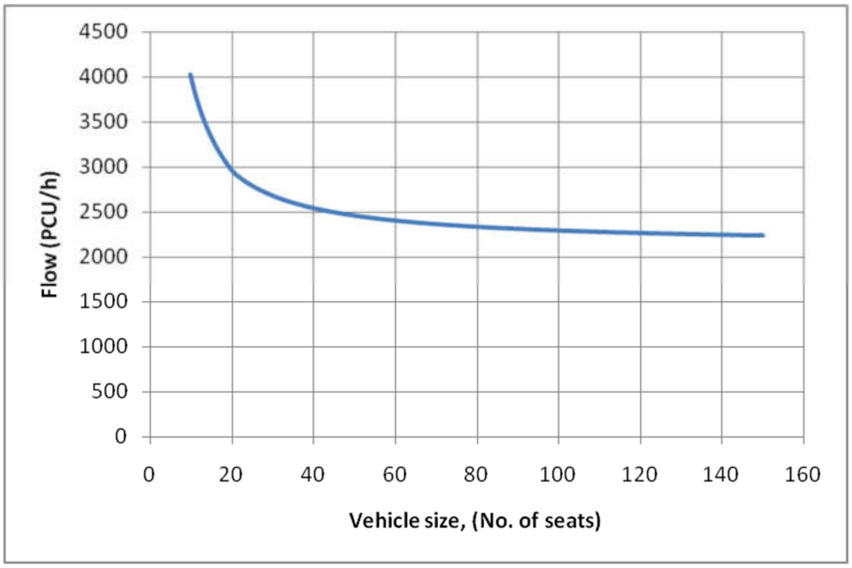


Figure 6.8: Segment 3 flow vs vehicle size

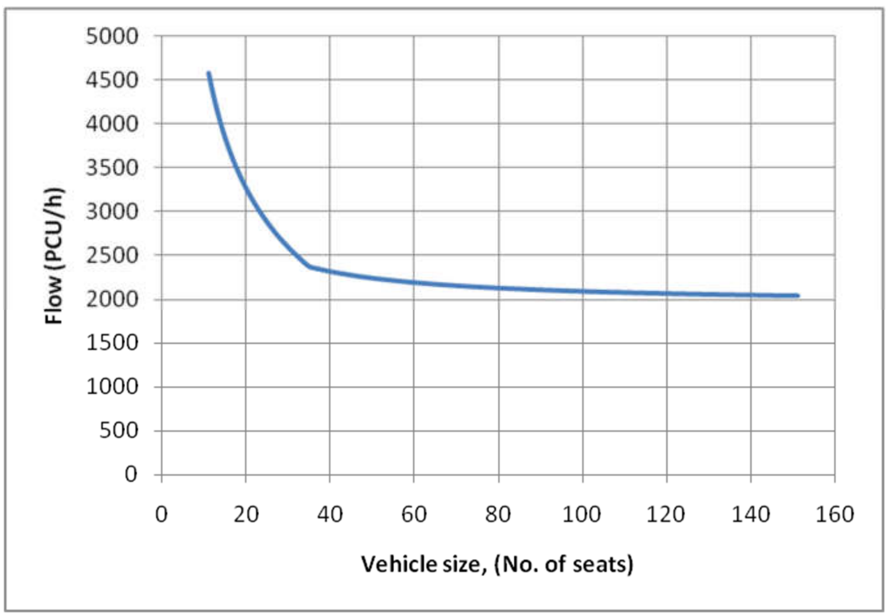


Figure 6.9: Segment 4 flow vs vehicle size

Table 6.4 below shows the resultant flows for segments 3 and 4 for selected vehicle sizes. The vehicle sizes were selected to reflect the bus sizes currently used in Kenya as well as common sizes for larger buses. It can be seen that when the bus size is very large, say above 80 seats, further increase in bus size results in smaller and smaller decreases in the resultant flows. The vehicle capacity is thus only limited by the second constraint to the objective function of the model. This is simply the maximum practical capacity for the various bus classes. For example, if a Class IV bus is selected, the bus capacity would be 69 seats; 104 and 150 seats, respectively, for single-articulated and bi-articulated buses.

Table 6.4: resultant flows for selected vehicle sizes along segments 3 & 4

	Flow (PCU/h)	
Vehicle size, (No. of seats)	**Segment 3**	**Segment 4**
10	4022	4853
14	3441	3986
26	2771	2811
29	2706	2641
33	2636	2451
41	2538	2308
51	2459	2236
62	2402	2183
80	2341	2129
100	2300	2091
120	2272	2066
150	2245	2041
180	2226	2024
200	2217	2016

CHAPTER 7. **DISCUSSION**

7.1 Introduction

One of the factors that influence the efficiency of a road-based public transport system is the transit vehicle size and type. Each type of vehicle has a role to play, and to some extent all may be complementary to one another as part of the overall public transport system. This study sought to quantify the demand for public transport along the Nairobi-Thika highway and to develop a method for identifying suitable transit vehicle sizes along the highway. In this chapter, the findings of the study are discussed with regard to the study data and results, analysis of results, and the relationships established and proposed methods.

7.2 The Study Data

The primary data for this research was collected along the Nairobi-Thika Highway. The secondary data was obtained from various sources including the internet and a bus body manufacturing company. Data collected included traffic counts, occupancy surveys, speed surveys and vehicle projected area surveys. The data collection methods used ensured high reliability and accuracy of the data.

Traffic volume counts were carried out at four locations along the study route for 12 hours between 6.30am and 6.30pm. This was repeated for three weekdays. The three day averages were assumed to be representative of all weekdays. Occupancy surveys were carried out alongside the traffic counts but for only one day. This was assumed to be representative of all weekdays. Speed surveys were carried out along one of the four route segments during low flow conditions. This was assumed to be representative of all the segments. Vehicle dimensions were obtained from two sources; a vehicle website for passenger cars; and a bus building company for buses.

7.3 Discussion of the Results

7.3.1 Traffic Volumes

The Average Daily Traffic along the Nairobi-Thika Highway has grown considerably since the upgrading of the highway. The 24 hour Nairobi-bound ADT established along the Muthaiga-Pangani segment in 2007 was 44,257 PCU (CES & APEC, 2007). This study established a 12-hour flow of 56,374PCU along the same segment. It was not possible to make a direct comparison between a 12-hour volume and a 24-hour volume. This growth is attributable to the traffic induced by the upgrading of the highway, and changes in land-use in the traffic generating areas served by the highway. Further, private car usage along the Nairobi-Thika Highway has grown considerably in the same period. Further, the growth in car use may be further attributed to increased car ownership.

The proportion of buses appear to have increased considerably since 2007 at the expense of 14-seater matatus, whose numbers have reduced. CES & APEC gave the matatu-bus ratio at 84% to 16% along the Muthaiga-Pangani segment while this study established the same as 53% to 47%. The proportion of larger buses also increases towards the city centre. This shift may be attributed to the increase in the passenger demand towards the CBD. However, private passenger cars still dominate the highway constituting an average of 71% of traffic on all route segments while PSVs constitute an average of 23% of the total vehicles. This shows a clear preference for private transport by car owners. In contrast, passenger cars constituted 33% of total traffic back in 2007.

7.3.2 Vehicle Occupancy

A preference for higher occupancy transit vehicles was observed. The 33-seater matatus had the highest occupancy rates along the route with occupancy above 100% along all segments except on the Githurai Roysambu segment; peaking along the Ruaraka-Muthaiga segment with 109% occupancy. This implies an average of 2.79 standees per bus. Occupancy for 51-seater matatus increased progressively from 84% along Githurai-Roysambu segment to 107% on the Muthaiga-Pangani segment. 10 and 14-seater matatus recorded reduced occupancy as they approached Nairobi CBD. This implies that higher capacity vehicles are desirable as the passenger demand increases.

Another observation was that the occupancy rates for matatus decrease as they approach the Nairobi CBD with 93% occupancy along the segment 1 falling to 89% along segment 4. In contrast, the rates for large buses increases from 84% to 107% over the same distance while those for minibuses increase from 98%, to 103% over the same distance. This apparent overloading of buses point to a preference for buses coupled with poor enforcement of overloading restrictions.

Occupancy rates for matatus also fell from 13.1 persons in 2007 to 12.7 persons in 2015. This reduction further reinforces the notion of diminishing importance of the 14-seater matatu along the highway. CES & APEC (2007) did not distinguish minibuses and large buses hence it was not possible to compare their findings on bus occupancy with data from this study. However, the study gave the average bus occupancy as 37.5 in 2007.

Challenges were encountered in the collection of occupancy data using the windshield method due to the high speed of moving vehicles. This was especially so in the case of buses, hence the accuracy was dependent on human judgment.

7.3.3 Transit Demand

Data from classified traffic counts and occupancy surveys, taken simultaneously, was used to establish useful transit service parameters including: passenger loads, passenger load, the share of transit passengers among different modes, passenger-km values, and the level of utilization of transit service and thus the efficiency of various modes

This procedure is a quick alternative to a full scale ride-check as described by the Hickman (2003), Chu (2009), and Ceder (2012), for collecting passenger data. This approach differs from the traditional ride-check in that it disregards the origin and destination of a particular bus run. This reliance on cross-sectional traffic data eliminates two problems in a transit system such as the one in Kenya; sampling of representative bus runs and the multiplicity of origins and terminals of PSVs operating along routes. The method compares well to that used by Maparu and Pandit (2010).

The results of transit ridership show a general trend whereby most of the parameters determined correlate with the distance from the Nairobi CBD. Passenger-loads, passenger-km and the level of utilization of the supplied seats increased progressively towards the CBD. It was also seen that large PSVs take a progressively greater share of the passenger loads as they move towards the CBD. It was also found out that, large buses (42-62 seats) covered the greatest percentage of the passenger-km among PSVs with 41%. Minibuses (33-seater) are second covering 32%, 14-seater matatus follow with 26% while 10-seater matatus covered about 1% of the passenger-km along the study route. Private and public transport vehicles covered 21.4% and 78.6% of the passenger-km respectively. These finding show the dominance of public transport over private transport along the route.

In contrast to the passenger-km, the seat-km values computed using the developed procedure showed a marked dominance of the supply of seat-km by private cars covering 39% against large buses which covered 24% of the overall seat-km. Among PSVs, the large buses still led with 41% against 29% each for minibuses and 14-seater matatus respectively, and 1% for 10-seater matatus

7.3.4 Speed

Speed data in this study was collected along Segment 2 (Roysambu-Ruaraka) by measuring vehicle speeds over a predefined section of roadway. In contrast, CES & APEC (2007) used floating car method to collect journey speeds. Along the Roysambu-Ruaraka segment, this research established an average speed of 82.9km/h while the earlier study reported an average car speed of 63.9km/h along the same section. The increase in speed can be attributed to the expansion of the highway in 2012 resulting in higher vehicle speeds. 14-seater matatus followed with 77.4km/h, 10-seater matatus with 73.5km/h, 51-seater buses with 73.4km/hr, 26-seater minibuses with 72.8km/h, 62-seater buses with 69km/hr, and 33-seater buses with 68.2km/h. Generally, smaller vehicles had higher speeds than larger vehicles.

7.3.5 Vehicle Projected Plan Area

The average passenger car occupies a gross area of 7.74 square metres; which is just slightly less that the gross area occupied by 14-seater matatu at 7.96 square metres. As a result, a passenger car provides about 1.55m^2 per seat while the 14-seater matatu provides 0.57m^2. A 26-seater minibus has an area of 14.06 square metres while the largest bus has an area of 29.29 square metres. Chandra and Sikdar (2000) had obtained 7.28m^2 average projected area for passenger cars, and 23m^2 for buses and trucks. 51-seater buses take the least passenger sitting space at 0.45m^2 per seat, even less than 62-seater buses at 0.47m^2 per seat. This can be attributed to the fact that 62-seater buses are usually used for long distance travel and hence, more passenger space is provided for comfort. However, the general trend is as expected whereby the area taken up by a seat varies inversely with the vehicle size. The number of seats in the current buses currently in service compares well with the proposed standards by the Kenya Bureau of Standards (DKS 372: 2018). Only the 26-seater and the 62-seater buses have exceeded the maximum number of seats by 1 and 2 seats, respectively.

7.3.6 Bus Classification and Capacities According to KEBS Standards (DKS 372: 2018)

A rigid body bus can carry up to 69 passengers if it is built and fitted as per the proposed standards (DKS 372: 2018). Space efficiency was found to be maximum in the medium-sized buses (Classes III & IV). The efficiency reduces slightly as the bus size increases or reduces further. The reduced space efficiency for the very large buses is due to the extra doors, wider doors and wider gangways required for these buses. It should be noted that no consideration was made in this study for standing passengers. This is because the Kenya Traffic Act (2009) outlaws the carrying of standees in transit vehicles. Single-articulated and bi-articulated buses can therefore carry up to 104 and 150 sitting passengers respectively. However, the turning capabilities vis a vis the limits set out in the standards would, potentially, introduce further limits on these maximum capacities. A review of the Kenya Traffic Act to allow standing passengers would lead to an increase in the maximum capacities of the buses that allow standees.

7.4 The Transit Vehicle Size Selection Model

7.4.1 Vehicle Size vs Occupancy Rates

For the first two segments of the study moderate correlation was established between vehicle size and occupancy rates, with r-squared values of 0.612 and 0.674 respectively. From the modeled values, the vehicle size that would achieve the highest levels of occupancy could be obtained at about 36 and 38 seats for the first and second segment respectively. For segments 3 and 4, the relationship between vehicle size and occupancy yielded straight curves. Hence, the maximum occupancy rates could not be established along those segments. For this relationship to be determined with greater certainty, occupancy data should be collected on more vehicle sizes.

7.4.2 Vehicle Size vs Passenger Car Units

The passenger car unit formula proposed by Chandra and Sikdar (2000) was calibrated for low flow conditions and level terrain along segment 2. That way PCU values could theoretically be obtained for any vehicle size. By setting the PCU value of a passenger car at one, the PCU value for any vehicle size could be established, knowing its speed and its projected area on the road. The PCU values obtained from this method compare well with those given used by Kenya's Ministry of Roads (MOR, 1987). For example, the PCU of a 14-seater matatu was established as 1.1, as compared to the 1.0 given by the road design manual. While the same manual gives a PCE value of 2.0 for buses, the findings of this study established a range of values for different bus sizes; ranging from 2.1 for a 26-seater bus to 4.5 for a 62-seater bus. The dynamic PCU factors proved advantageous as they allow determination of PCU values for almost any vehicle size.

7.4.3 Vehicle Size Selection

Optimal bus size entails trade-offs between vehicle size and operational variables for a given frequency of service (Ceder (2007). Most of the earlier models concluded that it was more efficient to use smaller buses at higher frequencies (dell' Olio et al, 2012). The use of smaller buses offers passengers a better service frequency for a given service capacity, but costs more to operate per seat provided. Most of the earlier models for vehicle size optimization deal with operator and user cost minimization. As a result, most of them are data intensive and thus difficult to apply to the highly atomized nature of public transport in Kenya. For example, passenger waiting times proved difficult to measure because of the multiplicity of vehicle sizes, origin and destinations, irregular service frequencies and general preferences for certain public transport providers.

As opposed to cost minimization, the proposed model gives the resultant flows in PCU of public transport vehicles that would theoretically result from the selection of a particular vehicle size. The input variables for this model are occupancy rates and vehicle PCU value. The correlation between occupancy rates was not very strong. This may be attributed to inadequate data for vehicle sizes. The model was applied along the four segments of the study route. Along segments 1 and 2, a minimization of the flow function was possible and thus the optimum vehicle sizes could be established. The optimum vehicle sizes were established as 45 and 56 seats respectively. For segments 3 and 4, the optimum vehicle size could not be determined but the model allows computation of the resultant flows for any vehicle size.

The proposed model thus offers a simplified approach to vehicle size selection. It can be used to guide policy on transit vehicle size restrictions. For instance, it can be used to determine how close to the city centre certain vehicle sizes should be allowed. Hence, suitable locations for transfer stations and terminals for upcountry vehicles can be identified. However; further investigation is required to identify more variables that have an influence on vehicle size in uncoordinated bus systems.

CHAPTER 8. **CONCLUSIONS & RECOMMENDATIONS**

8.1 Conclusions

The main objective of this study was to develop and apply a model for selecting suitable transit vehicle sizes along the Nairobi-Thika Highway. The research questions and objectives presented in Chapter 1 were addressed and the following conclusions drawn:

- About 73% of vehicles along the Nairobi-Thika highway are private cars and goods vehicles. On the other hand, public transport vehicles contribute 27% of the traffic. This shows the private car is a significant contributor to traffic volumes along the highway.
- Transit ridership was obtained in terms of passenger loads and vehicle kilometres. Daily transit passenger loads increased from 133,962 passengers along Segment 1, to 290,775 passengers along segment 4. 1,765,447 passenger-kilometers daily were covered on public transport along the study route. Most ridership parameters increase towards the City Centre. The efficiency of the service also increases in the same direction. Public service vehicles take an increasingly greater share of the passenger loads as they approach the City Centre while, private and public transport vehicles covered 21.4% and 78.6% of the passenger-km respectively. These finding show the dominance of public transport over private transport along the route. 51-seater buses carry the most passengers along the highway and cover the most passenger-kilometres among PSVs, taking 41% of the daily commuter passenger-kilometres.
- Minibuses attract the highest occupancy rates along the first two segments (Githurai-Roysambu and Roysambu-Ruaraka) while large buses attract higher occupancy rates along the two segments closer to the CBD (Ruaraka-Muthaiga and Muthaiga-Pangani). Along the first two segments, 33-seater buses exhibited the highest occupancy rates, meaning that using very small vehicles or very large buses along these two segments would result in reduced occupancy rates. 51-seater buses had higher occupancy rates along the last two segments. This means that higher occupancy vehicles would achieve greater levels of occupancy along these segments. The relationship between occupancy rates and bus size would require a greater segregation of bus sizes during collection of occupancy data. Such segregation might render the visual occupancy survey method unsuitable for occupancy data collection.

- Smaller vehicles achieve greater speeds along the highway. Larger transit vehicles occupy less road space per passenger seat than smaller ones. Dynamic PCE values established in this study compare well with the traditional values, while providing greater flexibility in determining PCE values for any size of vehicle. The traditional conversion factors, as given in the Kenya Road Design Manual (1987), understate PCE values for large buses. Passenger Car Equivalence varies proportionately with the seat capacity of vehicles.
- A model was proposed in this study that relates vehicle size to the resultant flow for a selected vehicle size. Flow is a measure of a vehicle's contribution to roadway congestion. Optimum vehicle sizes were determined for the first two segments as 45 and 56 seats respectively. These would minimize roadway congestion for along these segments. Along segments 3and 4, the flows that would result from the selection of a particular vehicle size for the peak passenger flows were established.

8.2 Recommendations

The following recommendations are made from the findings of this study:

- The attractiveness of public transit along the route should be improved. Investigations should be carried out on the causes of increased passenger cars along the highway. The effectiveness of potential transit service improvement measures should be investigated.. Stated preference surveys should be carried out on transit users along the road as well as the public transport operators in order to more accurately explain the growing preference of higher-occupancy vehicles.
- Onboard surveys should be used for occupancy surveys for large vehicles, as opposed to the windshield method. This would allow further separation of bus sizes and that way, the relationship between bus size and the occupancy rates can be established to a higher precision. The use of automatic data collection using technologies such as mobile-phone location data, GIS, remote sensing, video cameras, among others, should be explored with an aim to increase accuracy and economy in traffic data collection
- Dynamic Passenger Car Equivalence factors should be used in conversion of counts where applicable. This would result in a greater accuracy in flows and even geometric design for different roadway conditions.

- Vehicle turning characteristics for various bus types should be carried out for the the bus types specified in the Kenya Bureau of Standards specifications (DKS 372: 2018). This would allow further refinement of the second constraint to the objective function in the model developed in this study, that is, the maximum capacity for a vehicle of a particular class, $Z_{k\ max}$ (See Section 6.4).
- 46-seater buses should be the smallest bus allowed beyond the first segment (Githurai-Roysambu). Further investigations should be carried out on the effects of different vehicle sizes on bus stop parameters, including passenger waiting times, berth space requirements, boarding and alighting times, frequency, among others
- Transport demand management measures should be investigated to assess their suitability reversing the apparent shift from public transport to private cars. Factors such as passenger comfort, transit access, last mile connection, road pricing and parking pricing should be considered as potential transport demand management measures.
- An operator and user costs assessment should be carried out on the current transit system on the Nairobi-Thika Highway. This would take into account passenger waiting times as well as the economic aspects of various bus sizes.

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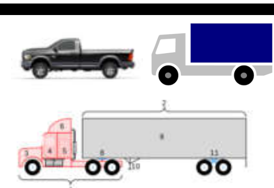
APPENDICES

Appendix A: Primary Data Collection Sample Sheets

A1: Traffic Count Tally Sheet for Public Service Vehicles

Public Transport Vehicles				
Traffic Count: Thika - Nairobi Highway Location: ______________________ Station Number: ______________________ Direction: ______________________________			Observer: ______________________________ Weather: ______________________________ Date: ________________________________ Page No.: ______________________________	
Veh Type / Time	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**
Illustration				
6:30 – 6:45				
6:45– 7:00				
7:00 – 7:15				

A2: Traffic Count Tally Sheet for Commercial and Private Vehicles

Commercial & Private Vehicles					
Traffic Count: Thika - Nairobi Highway Location: ______________________ Station Number: ______________________ Direction: ______________________________			Observer: ______________________________ Weather: ______________________________ Date: ________________________________ Page No.: ______________________________		
Veh Type / Time	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**
Illustration					
	Cars	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**
6:30 – 6:45					
6:45– 7:00					
7:00 – 7:15					

Appendix A3: Vehicle Occupancy Tally Sheet for Public Service Vehicles

<table>
<tr><th colspan="5">PUBLIC TRANSPORT OCCUPANCY</th></tr>
<tr><td colspan="3">Vehicle Occupancy: Thika - Nairobi Highway
Location: ______________________
Station Number: ______________________
Direction: ______________________________</td><td colspan="2">Observer: ______________________________
Weather: ______________________________
Date: ________________________________
Page No.: ______________________________</td></tr>
<tr><td>Veh Type
Time</td><td>10-Seater Matatus</td><td>14-seater matatus</td><td>33-seater bus</td><td>62-seater bus</td></tr>
<tr><td>6:30 – 6:45</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6:45– 7:00</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7:00 – 7:15</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7:15– 7:30</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7:30 – 7:45</td><td></td><td></td><td></td><td></td></tr>
<tr><td>7:45 – 8:00</td><td></td><td></td><td></td><td></td></tr>
</table>

A4: Vehicle Occupancy Tally Sheet for Commercial and Private Vehicles

Commercial & Private Vehicles				
Vehicle Occupancy: Thika - Nairobi Highway Location: ______________________ Station Number: ______________________ Direction: _______________________________			Observer: _______________________________ Weather: _______________________________ Date: _________________________________ Page No.: _______________________________	
Veh Type / Time	**Cars**	**Goods Vehicles (Pick-ups, trucks)**	**33-seater bus**	**62-seater bus**
6:30 – 6:45				
6:45– 7:00				
7:00 – 7:15				
7:15– 7:30				
7:30 – 7:45				
7:45 – 8:00				

A5: Travel Time Recording Sheet for Speed Study

Speed Data Collection Form							
	Traffic Count: Thika - Nairobi Highway Location: ______________________ Observer: ______________________ Date: ________________________________						
							
S.No	Passenger Cars	10-seaters	14-seaters	26-seaters	33-seaters	51-seaters	62-seaters
	Time (s)	Time (s)	Time (s)	Time (s)	Time (s)	Time (s)	Time (s)
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							

20							

A6: Private Passenger Car Vehicle Model Count Sheet

	Passenger Car Type Count									
	Traffic Count: Thika - Nairobi Highway Location: ______________________ Observer: ______________________ Date: ______________________________									
	Subcompact car		Saloon		Hatchback		SUV		Double cab pickup	
Model name										
Time	Tally	Number	Tally	Number	Tally	Number	Tally	Number	Tally	Number

Appendix B: DetailedTraffic Count Results

B1: Day 1 Traffic Count for Githurai-Roysambu Segment (1)

Traffic Count: Thika - Nairobi Highway			Observer: _____Irene							
Location:			Weather:							
Station Number: ____________________			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	737	80	46	15	6	121	290	158	81	**1534**
6:45– 7:00	769	57	15	3	0	123	255	162	61	**1445**
7:00 – 7:15	710	48	15	8	3	121	323	213	102	**1543**
7:15– 7:30	794	95	33	8	4	138	434	161	108	**1775**
7:30 – 7:45	623	47	7	2	3	99	368	220	82	**1451**
7:45 – 8:00	466	88	8	3	2	125	399	157	35	**1283**
8:00– 8:15	599	59	7	4	0	88	476	246	135	**1614**
8:15– 8:30	472	59	19	3	2	68	288	193	134	**1238**
8:30 – 8:45	447	60	14	2	0	37	181	132	60	**933**
8:45– 9:00	579	51	14	0	3	33	230	101	611	**1622**
9:00– 9:15	338	77	3	3	0	25	202	103	102	**853**
9:15– 9:30	387	48	15	3	3	4	129	116	50	**755**
9:30 – 9:45	401	47	7	2	3	24	113	611	28	**1236**
9:45– 10:00	284	87	13	2	15	38	125	69	46	**679**
10:00– 10:15	198	46	26	2	0	26	136	61	46	**541**
10:15– 10:30	280	68	6	7	0	13	105	49	26	**554**
10:30 – 10:45	315	66	6	0	0	11	81	22	33	**534**
10:45– 11:00	216	44	7	3	0	8	46	33	27	**384**
11:00– 11:15	299	66	8	2	0	7	62	35	25	**504**
11:15– 11:30	227	40	9	2	0	14	92	26	38	**448**
11:30 –11:45	279	92	13	2	0	10	88	30	27	**541**
11:45 – 12:00	275	102	35	0	0	14	64	24	13	**527**
12:00 – 12:15	241	62	8	0	0	27	79	28	26	**471**
12:15 – 12:30	355	69	14	3	2	8	95	20	18	**584**
12:30 – 12:45	238	60	20	3	0	20	83	30	18	**472**
12:45 – 1:00	164	73	16	0	0	10	76	14	24	**377**
1:00 – 1:15	220	80	11	3	0	13	77	31	17	**452**
1:15 – 1:30	317	70	13	0	2	9	72	18	21	**522**
1:30 – 1:45	257	131	13	0	0	15	124	16	13	**569**
1:45 – 2:00	200	99	17	3	2	11	101	17	15	**465**
2:00 – 2:15	235	33	11	0	0	7	69	17	18	**390**
2:15 – 2:30	269	62	17	0	2	15	85	29	9	**488**
2:30 – 2:45	340	69	18	0	0	21	53	10	25	**536**
2:45 – 3:00	274	68	25	2	2	21	83	17	15	**507**
3:00 – 3:15	207	81	7	0	0	6	88	10	22	**421**
3:15 – 3:30	149	59	5	2	2	2	68	13	19	**319**
3:30 – 3:45	165	68	9	2	2	4	61	6	15	**332**
3:45 – 4:00	205	69	16	2	2	4	74	16	24	**412**
4:00 – 4:15	183	60	8	0	0	6	50	8	17	**332**
4:15 – 4:30	248	58	14	2	2	5	70	14	18	**431**
4:30 – 4:45	120	35	5	2	2	6	79	16	30	**295**
4:45 – 5:00	110	19	7	2	0	3	101	21	28	**291**
5:00 – 5:15	247	121	7	5	0	8	73	17	21	**499**
5:15 – 5:30	240	86	11	4	4	5	98	11	28	**487**
5:30 – 5:45	268	65	22	8	0	5	92	25	24	**509**
5:45 – 6:00	209	50	4	2	2	4	102	24	33	**430**
6:00 – 6:15	187	58	17	3	4	3	301	142	215	**930**
6:15 – 6:30	187	32	7	4	4	4	183	92	97	**610**
Total	**15530**	**3164**	**648**	**128**	**78**	**1389**	**6924**	**3885**	**2680**	**34125**

B2: Day 1 Traffic Count for Roysambu-Ruaraka Segment (2)

Traffic Count: Thika - Nairobi Highway			Observer:							
Location: _______Kasarani____________			Weather:							
Station Number: _____________________			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	484	106	99	11	2	110	253	42	69	**1176**
6:45– 7:00	535	126	49	3	3	123	220	55	68	**1182**
7:00 – 7:15	374	121	25	4	4	44	154	48	77	**851**
7:15– 7:30	385	121	88	3	0	110	187	49	88	**1031**
7:30 – 7:45	429	99	88	2	0	165	123	58	103	**1067**
7:45 – 8:00	330	94	73	2	0	66	132	70	0	**767**
8:00– 8:15	462	62	121	3	3	77	264	125	209	**1326**
8:15– 8:30	341	66	44	17	0	91	253	154	198	**1164**
8:30 – 8:45	264	55	66	8	0	44	176	135	165	**913**
8:45– 9:00	220	49	31	10	3	33	253	165	165	**929**
9:00– 9:15	228	70	66	2	2	245	275	143	99	**1130**
9:15– 9:30	286	80	28	0	0	5	208	172	88	**867**
9:30 – 9:45	275	71	33	0	0	37	123	55	33	**627**
9:45– 10:00	374	107	7	2	0	37	99	55	55	**736**
10:00– 10:15	297	105	55	4	3	110	66	41	46	**727**
10:15– 10:30	198	114	33	6	0	143	58	110	26	**688**
10:30 – 10:45	339	88	53	2	0	146	363	198	22	**1211**
10:45– 11:00	330	88	26	0	0	132	132	35	22	**765**
11:00– 11:15	259	91	55	0	0	165	99	33	26	**728**
11:15– 11:30	216	84	50	2	2	110	93	29	38	**624**
11:30 –11:45	248	72	44	2	2	9	88	31	28	**524**
11:45 – 12:00	242	64	55	2	3	14	64	24	13	**481**
12:00 – 12:15	209	94	60	0	0	36	69	33	33	**534**
12:15 – 12:30	209	99	85	5	0	11	93	20	22	**544**
12:30 – 12:45	242	85	49	2	0	20	81	28	11	**518**
12:45 – 1:00	231	110	47	5	0	16	77	13	27	**526**
1:00 – 1:15	319	99	42	7	0	11	99	4	20	**601**
1:15 – 1:30	187	70	73	2	3	17	72	27	29	**480**
1:30 – 1:45	275	95	77	2	0	22	116	17	14	**618**
1:45 – 2:00	275	96	9	0	2	19	102	28	7	**538**
2:00 – 2:15	308	77	88	0	0	6	69	6	18	**572**
2:15 – 2:30	242	105	83	0	0	15	85	29	9	**568**
2:30 – 2:45	253	90	73	0	0	22	53	10	25	**526**
2:45 – 3:00	275	96	44	0	0	21	83	17	15	**551**
3:00 – 3:15	231	86	50	2	0	6	88	17	22	**502**
3:15 – 3:30	308	115	88	0	0	2	7	13	9	**542**
3:30 – 3:45	341	77	77	0	0	4	61	6	15	**581**
3:45 – 4:00	326	110	38	0	3	4	74	16	24	**595**
4:00 – 4:15	374	72	83	0	4	6	50	8	17	**614**
4:15 – 4:30	322	74	99	0	0	5	70	14	18	**602**
4:30 – 4:45	290	97	99	0	0	6	79	15	30	**616**
4:45 – 5:00	374	94	52	0	3	3	101	21	28	**676**
5:00 – 5:15	341	71	99	0	0	2	73	17	21	**624**
5:15 – 5:30	385	93	77	0	0	5	98	11	28	**697**
5:30 – 5:45	380	88	72	5	0	5	91	25	24	**690**
5:45 – 6:00	407	96	42	0	0	4	102	24	33	**708**
6:00 – 6:15	484	50	110	0	0	3	181	88	165	**1081**
6:15 – 6:30	352	36	55	0	2	5	169	123	93	**835**
Total	**15056**	**4208**	**2960**	**115**	**44**	**2292**	**5926**	**2457**	**2395**	**35453**

B3: Day 1 Traffic Count for Ruaraka-Muthaiga Segment (3)

Traffic Count: Thika - Nairobi Highway			Observer:							
Location: __________utalii___________			Weather:							
Station Number: ______________________			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	72	19	43	5	4	4	119	107	60	**433**
6:45– 7:00	112	0	54	0	0	3	128	108	44	**449**
7:00 – 7:15	208	3	11	10	4	4	140	90	53	**523**
7:15– 7:30	127	3	5	0	0	4	124	112	48	**423**
7:30 – 7:45	74	13	0	0	2	5	116	85	64	**359**
7:45 – 8:00	142	20	17	11	11	6	105	58	49	**419**
8:00– 8:15	10	7	8	5	3	10	60	70	40	**213**
8:15– 8:30	47	18	16	11	4	0	104	60	37	**297**
8:30 – 8:45	59	11	18	14	0	2	62	68	21	**255**
8:45– 9:00	60	25	47	10	4	2	93	70	33	**344**
9:00– 9:15	97	35	32	6	2	4	76	60	29	**341**
9:15– 9:30	141	39	59	6	3	2	84	57	36	**427**
9:30 – 9:45	90	13	49	6	6	0	87	64	32	**347**
9:45– 10:00	107	13	59	3	2	4	72	60	26	**346**
10:00– 10:15	101	24	49	5	3	2	74	52	32	**342**
10:15– 10:30	104	25	62	4	2	0	43	27	17	**284**
10:30 – 10:45	91	15	75	0	0	5	74	46	30	**336**
10:45– 11:00	125	11	70	15	2	4	57	36	21	**341**
11:00– 11:15	116	15	59	3	0	4	76	51	31	**355**
11:15– 11:30	70	8	55	0	0	4	57	26	31	**251**
11:30 –11:45	107	16	50	4	2	0	83	39	24	**325**
11:45 – 12:00	84	3	17	6	2	3	74	42	25	**256**
12:00 – 12:15	94	17	61	0	0	4	87	51	27	**341**
12:15 – 12:30	71	16	48	3	3	2	79	29	26	**277**
12:30 – 12:45	94	24	57	4	0	2	93	33	32	**339**
12:45 – 1:00	108	26	39	2	0	2	49	24	31	**281**
1:00 – 1:15	148	22	44	0	3	3	84	29	22	**355**
1:15 – 1:30	129	13	36	2	0	2	74	30	20	**306**
1:30 – 1:45	121	29	52	4	4	0	82	26	24	**342**
1:45 – 2:00	117	24	57	5	0	2	53	40	15	**313**
2:00 – 2:15	106	27	52	3	0	3	102	42	50	**385**
2:15 – 2:30	86	32	51	6	0	4	65	30	27	**301**
2:30 – 2:45	98	29	49	0	0	2	54	38	43	**313**
2:45 – 3:00	65	31	36	2	3	3	55	28	29	**252**
3:00 – 3:15	95	39	42	6	5	2	102	33	41	**365**
3:15 – 3:30	115	38	50	3	6	4	72	38	29	**355**
3:30 – 3:45	82	40	49	5	3	2	98	31	25	**335**
3:45 – 4:00	80	43	40	4	4	5	94	30	20	**320**
4:00 – 4:15	81	30	60	2	2	4	106	38	41	**364**
4:15 – 4:30	84	46	48	2	2	0	82	41	31	**336**
4:30 – 4:45	71	21	30	3	2	0	126	32	35	**320**
4:45 – 5:00	88	17	27	3	2	0	95	39	32	**303**
5:00 – 5:15	91	25	19	3	3	5	153	41	35	**375**
5:15 – 5:30	96	38	21	3	6	4	103	42	44	**357**
5:30 – 5:45	91	22	42	8	9	0	115	47	62	**396**
5:45 – 6:00	114	28	58	20	18	0	106	50	43	**437**
6:00 – 6:15	106	37	59	11	8	2	148	69	53	**493**
6:15 – 6:30	59	10	24	9	13	3	59	29	38	**244**
Total	**4634**	**1060**	**2006**	**237**	**152**	**132**	**4244**	**2348**	**1658**	**16471**

B4: Day 1 Traffic Count for Muthaiga-Pangani Segment (4)

Traffic Count: Thika - Nairobi Highway			Observer:							
Location: ________Pangani_______			Weather:							
Station Number: ______________________			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	Cars	Goods	10-14 seater	33-seater	62-seater	10-seater	14-seater	33-41-	42-62-	Total
6:30 – 6:45	174	37	17	5	0	48	12	90	34	**417**
6:45– 7:00	266	48	18	7	11	30	124	114	59	**677**
7:00 – 7:15	563	54	31	31	0	9	91	54	27	**860**
7:15– 7:30	246	107	22	2	0	17	83	158	64	**699**
7:30 – 7:45	206	87	9	0	0	20	98	98	52	**570**
7:45 – 8:00	259	79	4	0	0	11	110	116	41	**620**
8:00– 8:15	215	118	10	3	0	19	92	74	26	**557**
8:15– 8:30	121	47	8	2	2	14	85	94	38	**411**
8:30 – 8:45	125	64	21	2	0	10	81	117	35	**455**
8:45– 9:00	150	75	24	2	3	8	104	75	22	**463**
9:00– 9:15	150	80	9	2	3	6	96	102	31	**479**
9:15– 9:30	119	63	16	5	2	19	88	73	49	**434**
9:30 – 9:45	220	75	30	15	5	22	83	59	48	**557**
9:45– 10:00	139	62	10	6	4	10	65	68	57	**421**
10:00– 10:15	98	65	24	2	0	27	72	52	33	**373**
10:15– 10:30	125	74	28	0	0	32	91	55	35	**440**
10:30 – 10:45	121	49	13	2	0	24	93	54	27	**383**
10:45– 11:00	163	65	26	2	0	19	94	51	30	**450**
11:00– 11:15	205	70	8	2	0	18	70	53	40	**466**
11:15– 11:30	123	87	22	3	2	21	82	49	36	**425**
11:30 –11:45	160	113	21	6	0	28	99	42	37	**506**
11:45 – 12:00	112	95	49	5	0	19	116	49	32	**477**
12:00 – 12:15	191	70	16	3	0	15	85	58	14	**452**
12:15 – 12:30	214	79	25	18	0	24	106	41	31	**538**
12:30 – 12:45	130	84	22	24	0	11	80	38	28	**417**
12:45 – 1:00	167	63	8	0	0	16	95	57	19	**425**
1:00 – 1:15	167	65	79	2	0	18	110	61	20	**522**
1:15 – 1:30	224	70	9	4	0	25	95	73	25	**525**
1:30 – 1:45	152	59	16	3	0	15	70	46	42	**403**
1:45 – 2:00	128	49	7	0	0	14	95	32	49	**374**
2:00 – 2:15	141	75	9	2	0	17	92	36	17	**389**
2:15 – 2:30	108	50	219	5	4	16	83	42	19	**546**
2:30 – 2:45	132	55	8	0	0	18	85	31	21	**350**
2:45 – 3:00	121	62	17	0	0	16	87	32	32	**367**
3:00 – 3:15	165	79	28	3	0	18	75	40	27	**435**
3:15 – 3:30	195	24	22	8	0	20	84	40	35	**428**
3:30 – 3:45	197	80	9	6	0	20	101	36	25	**474**
3:45 – 4:00	159	95	36	11	3	18	85	35	28	**470**
4:00 – 4:15	180	95	46	8	0	18	84	38	31	**500**
4:15 – 4:30	168	91	40	6	0	15	77	39	29	**465**
4:30 – 4:45	162	83	38	11	3	16	71	54	27	**465**
4:45 – 5:00	117	119	41	9	4	11	69	41	47	**458**
5:00 – 5:15	187	92	27	6	5	21	105	47	57	**547**
5:15 – 5:30	126	63	21	11	3	11	65	42	26	**368**
5:30 – 5:45	189	91	71	8	4	9	61	48	42	**523**
5:45 – 6:00	196	79	83	24	13	13	64	29	36	**537**
6:00 – 6:15	119	43	28	11	11	6	62	53	26	**359**
6:15 – 6:30	108	44	22	0	6	4	44	40	28	**296**
Total	**8176**	**3473**	**1367**	**287**	**88**	**836**	**4059**	**2826**	**1634**	**22773**

B5: Day 2 Traffic Count for Githurai-Roysambu Segment (1)

Traffic Count: Thika - Nairobi			Observer: _____Irene							
Location:			Weather:							
Station Number:			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	670	72	41	13	5	110	263	143	73	**1390**
6:45– 7:00	699	51	13	2	0	111	231	147	55	**1309**
7:00 – 7:15	645	43	13	7	2	110	293	193	92	**1398**
7:15– 7:30	721	86	30	7	3	125	394	146	98	**1610**
7:30 – 7:45	566	42	6	1	2	90	334	200	74	**1315**
7:45 – 8:00	423	80	7	2	1	113	362	142	31	**1161**
8:00– 8:15	544	53	6	3	0	80	432	223	122	**1463**
8:15– 8:30	429	53	17	2	1	61	261	175	121	**1120**
8:30 – 8:45	406	54	12	1	0	33	164	120	54	**844**
8:45– 9:00	526	46	12		2	30	209	91	555	**1471**
9:00– 9:15	307	70	2	2	0	22	183	93	92	**771**
9:15– 9:30	351	43	13	2	2	3	117	105	45	**681**
9:30 – 9:45	364	42	6	1	2	21	102	555	25	**1118**
9:45– 10:00	258	79	11	1	13	34	113	62	41	**612**
10:00– 10:15	180	41	23	1	0	23	123	55	41	**487**
10:15– 10:30	254	61	5	6	0	11	95	44	23	**499**
10:30 – 10:45	286	60	5		0	10	73	20	30	**484**
10:45– 11:00	196	40	6	2	0	7	41	30	24	**346**
11:00– 11:15	271	60	7	1	0	6	56	31	22	**454**
11:15– 11:30	206	36	8	1	0	12	83	23	34	**403**
11:30 –11:45	253	83	11	1	0	9	80	27	24	**488**
11:45 – 12:00	250	92	31	0	0	12	58	21	11	**475**
12:00 – 12:15	219	56	7	0	0	24	71	25	23	**425**
12:15 – 12:30	322	62	12	2	1	7	86	18	16	**526**
12:30 – 12:45	216	54	18	2	0	18	75	27	16	**426**
12:45 – 1:00	149	66	14	0	0	9	69	12	21	**340**
1:00 – 1:15	200	72	10	2	0	11	70	28	15	**408**
1:15 – 1:30	288	63	11	0	1	8	65	16	19	**471**
1:30 – 1:45	233	119	11	0	0	13	112	14	11	**513**
1:45 – 2:00	181	90	15	2	1	10	91	15	13	**418**
2:00 – 2:15	213	30	10	0	0	6	62	15	16	**352**
2:15 – 2:30	244	56	15	0	1	13	77	26	8	**440**
2:30 – 2:45	309	62	16	0	0	19	48	9	22	**485**
2:45 – 3:00	249	61	22	1	1	19	75	15	13	**456**
3:00 – 3:15	188	73	6	0	0	5	80	9	20	**381**
3:15 – 3:30	135	53	4	1	1	1	61	11	17	**284**
3:30 – 3:45	150	61	8	1	1	3	55	5	13	**297**
3:45 – 4:00	186	62	14	1	1	3	67	14	21	**369**
4:00 – 4:15	166	54	7	0	0	5	45	7	15	**299**
4:15 – 4:30	225	52	12	1	1	4	63	12	16	**386**
4:30 – 4:45	109	31	4	1	1	5	71	14	27	**263**
4:45 – 5:00	100	17	6	1	0	2	91	19	25	**261**
5:00 – 5:15	224	110	6	4	0	7	66	15	19	**451**
5:15 – 5:30	218	78	10	3	3	4	89	10	25	**440**
5:30 – 5:45	243	59	20	7	0	4	83	22	21	**459**
5:45 – 6:00	190	45	3	1	1	3	92	21	30	**386**
6:00 – 6:15	170	52	15	2	3	2	273	129	195	**841**
6:15 – 6:30	170	29	6	3	3	3	166	83	88	**551**
Total	**14102**	**2854**	**567**	**91**	**53**	**1241**	**6270**	**3237**	**2412**	**30827**

B6: Day 2 Traffic Count for Roysambu-Ruaraka Segment (2)

Traffic Count: Thika - Nairobi			Observer:							
Location:			Weather:							
Station Number:			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	440	96	90	10	1	100	230	38	62	**1067**
6:45– 7:00	486	114	44	2	2	111	200	50	61	**1070**
7:00 – 7:15	340	110	22	3	3	40	140	43	70	**771**
7:15– 7:30	350	110	80	2	0	100	170	44	80	**936**
7:30 – 7:45	390	90	80	1	0	150	111	52	93	**967**
7:45 – 8:00	300	85	66	1	0	60	120	63		**695**
8:00– 8:15	420	56	110	2	2	70	240	113	190	**1203**
8:15– 8:30	310	60	40	15	0	82	230	140	180	**1057**
8:30 – 8:45	240	50	60	7	0	40	160	122	150	**829**
8:45– 9:00	200	44	28	9	2	30	230	150	150	**843**
9:00– 9:15	207	63	60	1	1	222	250	130	90	**1024**
9:15– 9:30	260	72	25	0	0	4	189	156	80	**786**
9:30 – 9:45	250	64	30	0	0	33	111	50	30	**568**
9:45– 10:00	340	97	6	1	0	33	90	50	50	**667**
10:00– 10:15	270	95	50	3	2	100	60	37	41	**658**
10:15– 10:30	180	103	30	5	0	130	52	100	23	**623**
10:30 – 10:45	308	80	48	1	0	132	330	180	20	**1099**
10:45– 11:00	300	80	23	0	0	120	120	31	20	**694**
11:00– 11:15	235	82	50	0	0	150	90	30	23	**660**
11:15– 11:30	196	76	45	1	1	100	84	26	34	**563**
11:30 –11:45	225	65	40	1	1	8	80	28	25	**473**
11:45 – 12:00	220	58	50	1	2	12	58	21	11	**433**
12:00 – 12:15	190	85	54	0	0	32	62	30	30	**483**
12:15 – 12:30	190	90	77	4	0	10	84	18	20	**493**
12:30 – 12:45	220	77	44	1	0	18	73	25	10	**468**
12:45 – 1:00	210	100	42	4	0	14	70	11	24	**475**
1:00 – 1:15	290	90	38	6	0	10	90	3	18	**545**
1:15 – 1:30	170	63	66	1	2	15	65	24	26	**432**
1:30 – 1:45	250	86	70	1	0	20	105	15	12	**559**
1:45 – 2:00	250	87	8	0	1	17	92	25	6	**486**
2:00 – 2:15	280	70	80	0	0	5	62	5	16	**518**
2:15 – 2:30	220	95	75	0	0	13	77	26	8	**514**
2:30 – 2:45	230	81	66	0	0	20	48	9	22	**476**
2:45 – 3:00	250	87	40	0	0	19	75	15	13	**499**
3:00 – 3:15	210	78	45	1	0	5	80	15	20	**454**
3:15 – 3:30	280	104	80	0	0	1	6	11	8	**490**
3:30 – 3:45	310	70	70	0	0	3	55	5	13	**526**
3:45 – 4:00	296	100	34	0	2	3	67	14	21	**537**
4:00 – 4:15	340	65	75	0	3	5	45	7	15	**555**
4:15 – 4:30	292	67	90	0	0	4	63	12	16	**544**
4:30 – 4:45	263	88	90	0	0	5	71	13	27	**557**
4:45 – 5:00	340	85	47	0	2	2	91	19	25	**611**
5:00 – 5:15	310	64	90	0	0	1	66	15	19	**565**
5:15 – 5:30	350	84	70	0	0	4	89	10	25	**632**
5:30 – 5:45	345	80	65	4	0	4	82	22	21	**623**
5:45 – 6:00	370	87	38	0	0	3	92	21	30	**641**
6:00 – 6:15	440	45	100	0	0	2	164	80	150	**981**
6:15 – 6:30	320	32	50	0	1	4	153	111	84	**755**
Total	**13683**	**3810**	**2681**	**88**	**28**	**2066**	**5372**	**2215**	**2162**	**32105**

Appendix B7: Day 2 Traffic Count for Ruaraka-Muthaiga Segment (3)

Traffic Count: Thika - Nairobi			Observer:							
Location:			Weather:							
Station Number:			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	65	17	39	4	3	3	108	97	54	**390**
6:45– 7:00	101		49			2	116	98	40	**406**
7:00 – 7:15	189	2	10	9	3	3	127	81	48	**472**
7:15– 7:30	115	2	4			3	112	101	43	**380**
7:30 – 7:45	67	11			1	4	105	77	58	**323**
7:45 – 8:00	129	18	15	10	10	5	95	52	44	**378**
8:00– 8:15	9	6	7	4	2	9	54	63	36	**190**
8:15– 8:30	42	16	14	10	3	0	94	54	33	**266**
8:30 – 8:45	53	10	16	12		1	56	61	19	**228**
8:45– 9:00	54	22	42	9	3	1	84	63	30	**308**
9:00– 9:15	88	31	29	5	1	3	69	54	26	**306**
9:15– 9:30	128	35	53	5	2	1	76	51	32	**383**
9:30 – 9:45	81	11	44	5	5	0	79	58	29	**312**
9:45– 10:00	97	11	53	2	1	3	65	54	23	**309**
10:00– 10:15	91	21	44	4	2	1	67	47	29	**306**
10:15– 10:30	94	22	56	3	1	0	39	24	15	**254**
10:30 – 10:45	82	13	68		0	4	67	41	27	**302**
10:45– 11:00	113	10	63	13	1	3	51	32	19	**305**
11:00– 11:15	105	13	53	2	0	3	69	46	28	**319**
11:15– 11:30	63	7	50		0	3	51	23	28	**225**
11:30 –11:45	97	14	45	3	1		75	35	21	**291**
11:45 – 12:00	76	2	15	5	1	2	67	38	22	**228**
12:00 – 12:15	85	15	55		0	3	79	46	24	**307**
12:15 – 12:30	64	14	43	2	2	1	71	26	23	**246**
12:30 – 12:45	85	21	51	3	0	1	84	30	29	**304**
12:45 – 1:00	98	23	35	1		1	44	21	28	**251**
1:00 – 1:15	134	20	40		2	2	76	26	20	**320**
1:15 – 1:30	117	11	32	1		1	67	27	18	**274**
1:30 – 1:45	110	26	47	3	3	0	74	23	21	**307**
1:45 – 2:00	106	21	51	4	0	1	48	36	13	**280**
2:00 – 2:15	96	24	47	2	0	2	92	38	45	**346**
2:15 – 2:30	78	29	46	5	0	3	59	27	24	**271**
2:30 – 2:45	89	26	44		0	1	49	34	39	**282**
2:45 – 3:00	59	28	32	1	2	2	50	25	26	**225**
3:00 – 3:15	86	35	38	5	4	1	92	30	37	**328**
3:15 – 3:30	104	34	45	2	5	3	65	34	26	**318**
3:30 – 3:45	74	36	44	4	2	1	89	28	22	**300**
3:45 – 4:00	72	39	36	3	3	4	85	27	18	**287**
4:00 – 4:15	73	27	54	1	1	3	96	34	37	**326**
4:15 – 4:30	76	41	43	1	1	0	74	37	28	**301**
4:30 – 4:45	64	19	27	2	1	0	114	29	31	**287**
4:45 – 5:00	80	15	24	2	1	0	86	35	29	**272**
5:00 – 5:15	82	22	17	2	2	4	139	37	31	**336**
5:15 – 5:30	87	34	19	2	5	3	93	38	40	**321**
5:30 – 5:45	82	20	38	7	8	0	104	42	56	**357**
5:45 – 6:00	103	25	52	18	16	0	96	45	39	**394**
6:00 – 6:15	96	33	53	10	7	1	134	62	48	**444**
6:15 – 6:30	53	9	21	8	11	2	53	26	34	**217**
Total	**4192**	**941**	**1803**	**194**	**116**	**94**	**3839**	**2113**	**1490**	**14782**

B8: Day 2 Traffic Count for Muthaiga-Pangani Segment (4)

Traffic Count: Thika - Nairobi			Observer:							
Location:			Weather:							
Station Number:			Date:							
Direction:			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	151	32	14	4	0	41	10	78	29	**359**
6:45– 7:00	241	43	16	6	10	27	112	103	53	**611**
7:00 – 7:15	511	49	28	28	0	8	82	49	24	**779**
7:15– 7:30	223	97	20	1	0	15	75	143	58	**632**
7:30 – 7:45	187	79	8	0	0	18	89	89	47	**517**
7:45 – 8:00	235	71	3	0	0	10	100	105	37	**561**
8:00– 8:15	195	107	9	2	0	17	83	67	23	**503**
8:15– 8:30	110	42	7	1	1	12	77	85	34	**369**
8:30 – 8:45	113	58	19	1	0	9	73	106	31	**410**
8:45– 9:00	136	68	21	1	2	7	94	68	20	**417**
9:00– 9:15	136	72	8	1	2	5	87	92	28	**431**
9:15– 9:30	108	57	14	4	1	17	80	66	44	**391**
9:30 – 9:45	200	68	27	13	4	20	75	53	43	**503**
9:45– 10:00	126	56	9	5	3	9	59	61	51	**379**
10:00– 10:15	89	59	21	1	0	24	65	47	30	**336**
10:15– 10:30	113	67	25		0	29	82	50	31	**397**
10:30 – 10:45	110	44	11	1	0	21	84	49	24	**344**
10:45– 11:00	148	59	23	1	0	17	85	46	27	**406**
11:00– 11:15	186	63	7	1	0	16	63	48	36	**420**
11:15– 11:30	111	79	20	2	1	19	74	44	32	**382**
11:30 –11:45	145	102	19	5	0	25	90	38	33	**457**
11:45 – 12:00	101	86	44	4	0	17	105	44	29	**430**
12:00 – 12:15	173	63	14	2	0	13	77	52	12	**406**
12:15 – 12:30	194	71	22	16	0	21	96	37	28	**485**
12:30 – 12:45	118	76	20	21	0	10	72	34	25	**376**
12:45 – 1:00	151	57	7	0	0	14	86	51	17	**383**
1:00 – 1:15	151	59	71	1	0	16	100	55	18	**471**
1:15 – 1:30	203	63	8	3	0	22	86	66	22	**473**
1:30 – 1:45	138	53	14	2	0	13	63	41	38	**362**
1:45 – 2:00	116	44	6	0	0	12	86	29	44	**337**
2:00 – 2:15	128	68	8	1	0	15	83	32	15	**350**
2:15 – 2:30	98	45	199	4	3	14	75	38	17	**493**
2:30 – 2:45	120	50	7	0	0	16	77	28	19	**317**
2:45 – 3:00	110	56	15	0	0	14	79	29	29	**332**
3:00 – 3:15	150	71	25	2	0	16	68	36	24	**392**
3:15 – 3:30	177	21	20	7	0	18	76	36	31	**386**
3:30 – 3:45	179	72	8	5	0	18	91	32	22	**427**
3:45 – 4:00	144	86	32	10	2	16	77	31	25	**423**
4:00 – 4:15	163	86	41	7	0	16	76	34	28	**451**
4:15 – 4:30	152	82	36	5	0	13	70	35	26	**419**
4:30 – 4:45	147	75	34	10	2	14	64	49	24	**419**
4:45 – 5:00	106	108	37	8	3	10	62	37	42	**413**
5:00 – 5:15	170	83	24	5	4	19	95	42	51	**493**
5:15 – 5:30	114	57	19	10	2	10	59	38	23	**332**
5:30 – 5:45	171	82	64	7	3	8	55	43	38	**471**
5:45 – 6:00	178	71	75	21	11	11	58	26	32	**483**
6:00 – 6:15	108	39	25	10	10	5	56	48	23	**324**
6:15 – 6:30	98	40	20	0	5	3	40	36	25	**267**
Total	7432	3136	1224	239	69	740	3671	2546	1462	**20519**

B9: Day 3 Traffic Count for Githurai-Roysambu Segment (1)

Traffic Count: Thika - Nairobi			Observer:							
Location:			Weather: ________Clear &							
Station Number: _____1____			Date:							
Direction: ____Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	482	16	4	0	1	3	72	18	27	**623**
6:45– 7:00	572	13	3	0	0	2	71	16	25	**702**
7:00 – 7:15	520	22	8	0	0	3	64	13	23	**653**
7:15– 7:30	495	51	4	0	0	6	68	17	20	**661**
7:30 – 7:45	425	35	3	0	0	3	66	15	26	**573**
7:45 – 8:00	450	58	12	0	0	4	69	14	21	**628**
8:00– 8:15	375	50	6	0	2	6	65	18	25	**547**
8:15– 8:30	380	36	5	0	0	3	62	13	23	**522**
8:30 – 8:45	450	30	4	0	0	2	76	18	21	**601**
8:45– 9:00	345	23	6	0	0	6	74	16	21	**491**
9:00– 9:15	485	15	8	0	0	1	56	14	20	**599**
9:15– 9:30	340	23	8	0	0	2	70	17	23	**483**
9:30 – 9:45	420	25	11	0	0	4	62	15	19	**556**
9:45– 10:00	340	6	16	0	0	3	61	17	25	**468**
10:00– 10:15	360	8	18	0	0	3	57	19	17	**482**
10:15– 10:30	460	10	10	0	0	1	51	29	25	**586**
10:30 – 10:45	160	10	4	0	0	1	60	20	24	**279**
10:45– 11:00	220	8	12	0	0	1	49	26	21	**337**
11:00– 11:15	320	10	17	0	0	1	48	17	22	**435**
11:15– 11:30	300	10	15	0	0	11	40	12	15	**403**
11:30 –11:45	320	5	4	0	0	2	43	22	18	**414**
11:45 – 12:00	240	21	1	0	0	3	39	11	16	**331**
12:00 – 12:15	260	24	5	0	0	1	62	14	16	**382**
12:15 – 12:30	240	20	4	0	0	2	65	16	23	**370**
12:30 – 12:45	180	19	21	0	1	6	64	15	21	**327**
12:45 – 1:00	240	20	9	0	0	3	54	10	14	**350**
1:00 – 1:15	100	14	4	0	1	2	42	5	11	**179**
1:15 – 1:30	340	16	3	0	0	3	50	12	9	**433**
1:30 – 1:45	240	8	5	0	0	1	59	11	17	**341**
1:45 – 2:00	330	9	4	0	1	2	52	13	18	**429**
2:00 – 2:15	180	7	5	0	0	2	59	13	16	**282**
2:15 – 2:30	150	5	3	0	0	1	48	8	14	**229**
2:30 – 2:45	220	8	8	0	0	1	51	10	17	**315**
2:45 – 3:00	140	4	4	0	0	3	69	12	12	**244**
3:00 – 3:15	210	9	4	0	0	4	61	6	21	**315**
3:15 – 3:30	260	9	5	0	0	3	56	9	18	**360**
3:30 – 3:45	260	11	2	0	6	6	59	7	25	**376**
3:45 – 4:00	340	8	10	0	4	3	62	8	21	**456**
4:00 – 4:15	300	7	8	0	2	3	53	7	32	**412**
4:15 – 4:30	330	5	8	0	1	2	61	10	23	**440**
4:30 – 4:45	400	26	8	0	2	4	54	16	19	**529**
4:45 – 5:00	290	39	8	0	0	2	56	13	16	**424**
5:00 – 5:15	420	38	1	1	2	2	58	10	15	**547**
5:15 – 5:30	420	19	8	1	3	2	60	13	22	**548**
5:30 – 5:45	370	25	13	0	0	1	74	16	26	**525**
5:45 – 6:00	380	29	9	1	0	1	83	17	31	**551**
6:00 – 6:15	380	34	4	0	0	1	68	11	26	**524**
6:15 – 6:30	300	26	8	0	1	1	74	15	29	**454**
Total	**15739**	**924**	**350**	**3**	**27**	**133**	**2877**	**674**	**989**	**21716**

B10: Day 3 Traffic Count for Roysambu-Ruaraka Segment (2)

Traffic Count: Thika - Nairobi			Observer:							
Location: _Kasarani____________			Weather: ___________Clear &							
Station Number: ______2______			Date:							
Direction: ______Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods**	**10-14 seater**	**33-seater**	**62-seater**	**10-seater**	**14-seater**	**33-41-seater**	**42-62-seater**	**Total**
6:30 – 6:45	525	22	5	0	2	0	73	21	31	**679**
6:45– 7:00	649	10	4	0	0	2	72	57	56	**850**
7:00 – 7:15	566	13	11	1	1	0	50	36	40	**718**
7:15– 7:30	430	14	6	0	1	2	65	35	30	**583**
7:30 – 7:45	486	17	4	0	1	7	58	26	28	**627**
7:45 – 8:00	474	21	15	1	0	3	40	27	36	**617**
8:00– 8:15	528	37	8	0	3	10	54	34	40	**714**
8:15– 8:30	475	43	7	0	0	4	41	21	25	**616**
8:30 – 8:45	454	52	6	1	1	1	60	39	32	**646**
8:45– 9:00	446	62	8	0	0	5	53	32	29	**635**
9:00– 9:15	515	35	11	0	0	2	49	37	30	**679**
9:15– 9:30	504	48	11	0	0	2	51	34	40	**690**
9:30 – 9:45	457	60	14	0	1	1	60	47	11	**651**
9:45– 10:00	486	66	20	0	0	0	50	37	26	**685**
10:00– 10:15	527	47	23	0	1	0	70	35	22	**725**
10:15– 10:30	628	80	13	0	1	2	44	41	32	**841**
10:30 – 10:45	492	70	5	0	1	3	37	31	33	**672**
10:45– 11:00	400	52	15	1	1	0	45	34	36	**584**
11:00– 11:15	350	65	22	0	1	5	38	22	35	**538**
11:15– 11:30	458	72	19	0	1	2	43	27	29	**651**
11:30 –11:45	400	43	6	1	0	1	60	39	20	**570**
11:45 – 12:00	433	44	2	0	0	4	47	15	20	**565**
12:00 – 12:15	413	38	7	0	0	0	40	29	24	**551**
12:15 – 12:30	381	44	5	0	0	3	49	26	25	**533**
12:30 – 12:45	306	56	27	0	2	3	58	21	27	**500**
12:45 – 1:00	368	64	12	1	1	3	53	37	17	**556**
1:00 – 1:15	250	38	5	0	2	1	46	10	16	**368**
1:15 – 1:30	332	55	4	0	1	1	50	21	14	**478**
1:30 – 1:45	445	48	7	1	1	1	41	22	24	**590**
1:45 – 2:00	477	30	5	0	2	2	57	28	18	**619**
2:00 – 2:15	323	70	7	0	1	0	68	22	24	**515**
2:15 – 2:30	231	49	4	0	1	6	62	18	20	**391**
2:30 – 2:45	249	69	11	0	0	2	55	20	18	**424**
2:45 – 3:00	266	57	6	0	1	0	59	22	12	**423**
3:00 – 3:15	400	80	5	0	0	2	74	26	29	**616**
3:15 – 3:30	364	60	7	0	0	2	58	24	23	**538**
3:30 – 3:45	300	76	3	0	8	2	56	24	18	**487**
3:45 – 4:00	401	85	13	0	5	1	65	20	23	**613**
4:00 – 4:15	384	71	10	0	3	1	69	24	30	**592**
4:15 – 4:30	323	40	11	0	2	0	88	43	30	**537**
4:30 – 4:45	508	55	10	1	3	3	72	23	21	**696**
4:45 – 5:00	356	53	11	0	0	1	65	40	34	**560**
5:00 – 5:15	486	54	2	2	3	4	79	29	30	**689**
5:15 – 5:30	434	52	11	2	4	3	77	28	32	**643**
5:30 – 5:45	347	55	17	0	0	1	84	25	28	**557**
5:45 – 6:00	319	51	12	2	0	0	74	35	27	**520**
6:00 – 6:15	303	71	5	1	1	2	74	44	34	**535**
6:15 – 6:30	308	42	10	0	2	2	88	31	37	**520**
Total	**19957**	**2436**	**462**	**15**	**59**	**102**	**2821**	**1419**	**1316**	**28587**

B11: Day 3 Traffic Count for Ruaraka-Muthaiga Segment (3)

Traffic Count: Thika - Nairobi			Observer:							
Location:			Weather: _______Clear &							
Station Number: _____3____			Date:							
Direction: _______Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods**	**10-14 seater**	**33-seater**	**62-seater**	**10-seater**	**14-seater**	**33-41-seater**	**42-62-seater**	**Total**
6:30 – 6:45	265	13	2	2	1	0	21	20	4	**328**
6:45– 7:00	530	12	3	1	0	2	78	79	32	**737**
7:00 – 7:15	940	32	3	2	0	0	138	97	65	**1277**
7:15– 7:30	970	24	2	2	2	2	105	106	49	**1262**
7:30 – 7:45	770	24	0	3	1	7	105	105	63	**1078**
7:45 – 8:00	805	14	0	1	0	3	91	82	45	**1041**
8:00– 8:15	860	37	0	1	4	10	144	88	52	**1196**
8:15– 8:30	596	39	1	0	0	4	100	68	41	**849**
8:30 – 8:45	415	48	6	1	1	1	72	52	32	**628**
8:45– 9:00	422	48	11	0	2	5	89	56	25	**658**
9:00– 9:15	475	40	13	0	0	2	78	49	34	**691**
9:15– 9:30	497	30	1	0	0	2	70	60	33	**693**
9:30 – 9:45	485	68	7	1	0	1	84	60	26	**732**
9:45– 10:00	415	55	4	1	0	0	47	43	27	**592**
10:00– 10:15	510	69	19	0	0	0	78	50	24	**750**
10:15– 10:30	365	68	15	0	0	2	71	49	30	**600**
10:30 – 10:45	505	75	19	0	0	3	73	41	25	**741**
10:45– 11:00	425	56	12	1	1	0	52	32	19	**598**
11:00– 11:15	370	89	9	1	0	5	65	53	27	**619**
11:15– 11:30	400	73	25	0	0	2	70	55	26	**651**
11:30 –11:45	403	61	11	0	0	1	64	55	19	**614**
11:45 – 12:00	444	68	7	0	0	4	67	36	24	**650**
12:00 – 12:15	389	48	3	2	1	0	55	27	23	**548**
12:15 – 12:30	390	65	12	0	1	3	70	31	14	**586**
12:30 – 12:45	400	43	18	0	0	3	61	33	21	**579**
12:45 – 1:00	380	62	18	0	0	3	61	25	21	**570**
1:00 – 1:15	350	50	14	2	1	1	60	31	20	**529**
1:15 – 1:30	385	72	10	0	1	1	76	28	17	**590**
1:30 – 1:45	337	60	14	2	1	1	65	25	15	**520**
1:45 – 2:00	375	65	13	0	0	2	65	31	19	**570**
2:00 – 2:15	430	53	7	3	2	0	73	34	14	**616**
2:15 – 2:30	365	49	15	5	1	6	59	31	16	**547**
2:30 – 2:45	385	52	14	1	0	2	59	28	12	**553**
2:45 – 3:00	430	60	10	0	0	0	73	31	19	**623**
3:00 – 3:15	411	73	15	1	3	2	67	33	22	**627**
3:15 – 3:30	395	65	7	0	0	2	75	27	26	**597**
3:30 – 3:45	419	60	8	1	1	2	56	35	24	**606**
3:45 – 4:00	330	46	11	2	1	1	61	25	21	**498**
4:00 – 4:15	265	56	11	2	2	1	56	33	19	**445**
4:15 – 4:30	360	45	14	1	0	0	73	30	28	**551**
4:30 – 4:45	355	45	7	2	0	3	80	43	17	**552**
4:45 – 5:00	439	51	11	0	0	1	104	41	31	**678**
5:00 – 5:15	475	50	3	6	4	4	87	41	31	**701**
5:15 – 5:30	510	50	12	0	1	3	105	46	18	**745**
5:30 – 5:45	437	59	17	6	0	1	102	52	28	**702**
5:45 – 6:00	437	25	5	6	0	0	115	60	28	**676**
6:00 – 6:15	380	64	14	4	0	2	161	75	48	**748**
6:15 – 6:30	310	38	8	2	3	2	113	63	19	**558**
Total	**22006**	**2449**	**461**	**65**	**35**	**102**	**3794**	**2295**	**1293**	**32500**

B12: Day 3 Traffic Count for Muthaiga-Pangani Segment (4)

Traffic Count: Thika - Nairobi			Observer:							
Location: _____Pangani_______			Weather: _________Clear &							
Station Number: ______4______			Date:							
Direction: ______Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 6:45	1150	16	5	0	0	3	38	31	51	**1294**
6:45– 7:00	1667	27	16	2	4	3	46	44	43	**1852**
7:00 – 7:15	1230	21	17	4	4	3	76	83	33	**1471**
7:15– 7:30	955	42	15	3	0	3	147	86	26	**1277**
7:30 – 7:45	1228	32	18	2	1	3	100	53	23	**1460**
7:45 – 8:00	954	56	25	1	1	7	209	145	44	**1442**
8:00– 8:15	931	54	26	4	2	6	72	75	52	**1222**
8:15– 8:30	1008	69	19	0	3	6	99	76	49	**1329**
8:30 – 8:45	1000	64	7	0	1	3	120	43	76	**1314**
8:45– 9:00	992	72	11	2	2	1	62	51	36	**1229**
9:00– 9:15	855	64	19	0	1	1	50	34	50	**1074**
9:15– 9:30	751	50	14	0	1	1	47	15	46	**925**
9:30 – 9:45	692	66	10	4	2	1	55	18	30	**878**
9:45– 10:00	700	54	18	0	1	0	57	26	36	**892**
10:00– 10:15	685	41	11	0	0	0	96	37	9	**879**
10:15– 10:30	653	36	21	0	0	3	109	34	25	**881**
10:30 – 10:45	590	70	23	1	1	1	93	29	40	**848**
10:45– 11:00	630	44	23	2	0	2	84	34	59	**878**
11:00– 11:15	529	20	4	1	1	1	85	39	28	**708**
11:15– 11:30	550	100	25	1	2	1	81	52	29	**841**
11:30 –11:45	574	64	16	2	0	1	92	32	29	**810**
11:45 – 12:00	705	84	14	0	0	1	73	28	28	**933**
12:00 – 12:15	596	51	17	1	0	1	90	11	39	**806**
12:15 – 12:30	635	54	12	4	0	1	55	20	28	**809**
12:30 – 12:45	748	61	17	2	0	1	90	16	45	**980**
12:45 – 1:00	745	47	17	0	0	5	58	32	21	**925**
1:00 – 1:15	100	20	5	0	0	3	78	30	28	**264**
1:15 – 1:30	386	16	8	4	0	1	36	16	5	**472**
1:30 – 1:45	838	128	40	0	1	1	50	32	32	**1122**
1:45 – 2:00	610	96	25	3	0	1	96	16	38	**885**
2:00 – 2:15	687	74	33	4	2	0	75	12	41	**928**
2:15 – 2:30	356	87	33	0	0	1	72	18	53	**620**
2:30 – 2:45	429	75	33	1	0	1	61	18	31	**649**
2:45 – 3:00	647	88	25	1	0	0	73	16	32	**882**
3:00 – 3:15	660	92	25	2	2	0	68	21	38	**908**
3:15 – 3:30	521	97	27	3	0	1	71	18	40	**778**
3:30 – 3:45	543	97	30	0	0	3	65	4	46	**788**
3:45 – 4:00	566	59	32	7	0	1	96	45	55	**861**
4:00 – 4:15	490	78	28	5	0	1	93	20	48	**763**
4:15 – 4:30	575	74	27	2	1	0	67	9	55	**810**
4:30 – 4:45	642	47	14	1	1	2	88	53	16	**864**
4:45 – 5:00	807	61	10	1	1	1	98	49	28	**1056**
5:00 – 5:15	823	52	12	6	0	4	94	46	28	**1065**
5:15 – 5:30	694	45	8	4	4	1	91	36	60	**943**
5:30 – 5:45	762	52	8	2	2	3	85	48	55	**1017**
5:45 – 6:00	741	42	6	7	1	0	117	41	53	**1008**
6:00 – 6:15	554	34	12	4	1	2	116	39	61	**823**
6:15 – 6:30	597	73	18	7	0	2	161	61	39	**958**
Total	**34781**	**2846**	**879**	**100**	**43**	**88**	**4035**	**1792**	**1857**	**46421**

Appendix C: Average DailyTraffic (PCU)

C1: Average DailyTraffic Along Githurai-Roysambu Segment (1)

Traffic Count: Thika - Nairobi			Observer:							
Location:			Weather: ________Clear &							
Station Number: _____1____			Date:							
Direction: ____Towards Nairobi____			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Traffic Volume**
6:30 – 7:30	2069	254	19	0	3	14	275	128	285	**3047**
7:30 – 8:30	1630	447	26	0	6	16	262	120	285	**2792**
8:30 – 9:30	1620	226	26	0	0	11	276	130	255	**2544**
9:30 – 10:30	1580	122	55	0	0	11	231	160	258	**2417**
10:30 – 11:30	1000	95	48	0	0	14	197	150	246	**1750**
11:30 –12:30	1060	174	14	0	0	8	209	126	219	**1810**
12:30 – 1:30	860	172	37	0	6	14	210	84	165	**1548**
1:30 – 2:30	900	71	17	0	3	6	218	90	195	**1500**
2:30 – 330	830	74	21	0	0	11	237	74	204	**1451**
3:30 – 4:30	1230	76	28	0	39	14	235	64	303	**1989**
4:30 – 5:30	1530	304	25	4	21	10	228	104	216	**2442**
5:30 – 6:30	1430	284	34	2	3	4	299	118	336	**2510**
Total	**15739**	**2299**	**350**	**6**	**81**	**133**	**2877**	**1348**	**2967**	**25800**

C2: Average DailyTraffic Along Roysambu-Ruaraka Segment (2)

Traffic Count: Thika - Nairobi			Observer:							
Location: _Kasarani____________			Weather: ___________Clear &							
Station Number: ______2______			Date:							
Direction: ______Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 7:30	2170	147	26	2	12	4	260	298	471	**3390**
7:30 – 8:30	1963	293	34	2	12	24	193	216	387	**3124**
8:30 – 9:30	1919	492	36	2	3	10	213	284	393	**3352**
9:30 – 10:30	2098	632	70	0	9	3	224	320	273	**3629**
10:30 – 11:30	1700	647	61	2	12	10	163	228	399	**3222**
11:30 –12:30	1627	422	20	2	0	8	196	218	267	**2760**
12:30 – 1:30	1256	532	48	2	18	8	207	178	222	**2471**
1:30 – 2:30	1476	492	23	2	15	9	228	180	258	**2683**
2:30 – 330	1279	664	29	0	3	6	246	184	246	**2657**
3:30 – 4:30	1408	679	37	0	54	4	278	222	303	**2985**
4:30 – 5:30	1784	534	34	10	30	11	293	240	351	**3287**
5:30 – 6:30	1277	546	44	6	9	5	320	270	378	**2855**
Total	**19957**	**6080**	**462**	**30**	**177**	**102**	**2821**	**2838**	**3948**	**36415**

C3: Average DailyTraffic Along Ruaraka-Muthaiga Segment (3)

Traffic Count: Thika - Nairobi			Observer:							
Location: _____Utalii___________			Weather: _______Clear &							
Station Number: _____3____			Date:							
Direction: _______Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 7:30	2705	202	10	14	9	4	342	604	450	**4340**
7:30 – 8:30	3031	284	1	10	15	24	440	686	603	**5094**
8:30 – 9:30	1809	415	31	2	9	10	309	434	372	**3391**
9:30 – 10:30	1775	649	45	4	0	3	280	404	321	**3481**
10:30 – 11:30	1700	731	65	4	3	10	260	362	291	**3426**
11:30 –12:30	1626	604	33	4	6	8	256	298	240	**3075**
12:30 – 1:30	1515	567	60	4	6	8	258	234	237	**2889**
1:30 – 2:30	1507	566	49	20	12	9	262	242	192	**2859**
2:30 – 330	1621	624	46	4	9	6	274	238	237	**3059**
3:30 – 4:30	1374	517	44	12	12	4	246	246	276	**2731**
4:30 – 5:30	1779	489	33	16	15	11	376	342	291	**3352**
5:30 – 6:30	1564	464	44	36	9	5	491	500	369	**3482**
Total	**22006**	**6112**	**461**	**130**	**105**	**102**	**3794**	**4590**	**3879**	**41179**

C4: Average DailyTraffic Along Muthaiga-Pangani Segment (4)

Traffic Count: Thika - Nairobi			Observer:							
Location: ________Pangani_______			Weather: _________Clear &							
Station Number: ______4______			Date:							
Direction: ______Towards			Page No.:			PUBLIC TRANSPORT				
Veh Type	**Cars**	**Goods Vehicles**	**10-14 seater vans**	**33-seater bus**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 7:30	5002	264	53	18	24	12	307	488	459	**6627**
7:30 – 8:30	4121	527	88	14	21	22	480	698	504	**6475**
8:30 – 9:30	3598	625	51	4	15	6	279	286	624	**5488**
9:30 – 10:30	2730	492	60	8	9	4	317	230	300	**4150**
10:30 – 11:30	2299	585	75	10	12	5	343	308	468	**4105**
11:30 –12:30	2510	632	59	14	0	4	310	182	372	**4083**
12:30 – 1:30	1979	359	47	12	0	10	262	188	297	**3154**
1:30 – 2:30	2491	962	131	14	9	3	293	156	492	**4551**
2:30 – 330	2257	879	110	14	6	2	273	146	423	**4110**
3:30 – 4:30	2174	769	117	28	3	5	321	156	612	**4185**
4:30 – 5:30	2966	511	44	24	18	8	371	368	396	**4706**
5:30 – 6:30	2654	502	44	40	12	7	479	378	624	**4740**
Total	**34781**	**7107**	**879**	**200**	**129**	**88**	**4035**	**3584**	**5571**	**56374**

Appendix D: Average Vehicle Occupancy (Excluding goods Vehicles)

D1: Average Vehicle Occupancy along Githurai-Roysambu Segment (1)

Vehicle Occupancy: Thika -		Observer:					
Location:		Weather:					
Station Number:		Date:					
Direction:		Page No.:					
Veh Type	**Cars**	**33-seater bus**	**62-seater bus**	**10-Seater Matatus**	**14-seater matatus**	**33-seater bus**	**51-seater bus**
6:30 – 7:00	1.70	15.00	39.50	7.75	13.83	33.00	49.44
7:00 – 7:30	1.65	17.25	19.00	8.63	13.92	33.29	50.94
7:30 – 8:00	1.54	31.50	56.50	10.00	14.30	33.18	52.33
8:00– 8:30	1.36	28.75	40.00	8.28	14.20	30.73	51.22
8:30 – 9:00	1.41	21.50	32.50	10.25	13.80	32.33	51.23
9:00– 9:30	1.31	10.13	10.33	9.17	13.79	32.28	49.31
9:30 – 10:00	1.38	25.61	12.38	10.63	13.83	32.06	50.35
10:00– 10:30	1.42	3.22	40.00	9.00	12.35	27.99	48.80
10:30 – 11:00	1.74	3.13	9.00	10.00	13.22	31.97	50.16
11:00– 11:30	1.88	13.17	20.00	6.00	13.31	29.90	49.13
11:30 –12:00	1.90	2.00	20.00	9.40	13.84	31.42	48.27
12:00 – 12:30	1.74	25.50	24.00	9.70	13.62	39.47	47.42
12:30 – 1:00	1.51	25.50	36.00	10.00	12.73	31.20	47.99
1:00 – 1:30	1.62	20.00	15.00	9.00	13.06	31.87	49.35
1:30 – 2:00	1.94	17.50	17.50	10.00	12.74	31.92	43.70
2:00 – 2:30	1.60	9.00	29.50	10.00	13.41	30.13	38.35
2:30 – 3:00	1.86	11.50	39.00	9.13	12.89	28.29	39.83
3:00 – 3:30	1.77	13.50	12.50	10.00	12.28	27.94	37.95
3:30 – 4:00	1.64	16.00	21.50	4.75	11.31	28.30	30.00
4:00 – 4:30	1.80	6.50	40.00	8.50	11.98	26.85	31.49
4:30 – 5:00	1.92	18.50	14.00	5.13	12.81	31.49	29.55
5:00 – 5:30	2.15	17.10	22.30	8.00	11.88	26.01	43.52
5:30 – 6:00	2.26	17.00	17.25	9.10	11.80	22.17	20.23
6:00 – 6:30	1.85	7.00	18.17	8.00	11.53	28.93	22.66
Average	**1.71**	**15.66**	**25.25**	**8.77**	**13.02**	**30.53**	**43.05**

D2: Average Vehicle Occupancy along Roysambu-Ruaraka Segment (2)

Vehicle Occupancy: Thika -		Observer:					
Location: Kasarani_____		Weather:					
Station Number:		Date:					
Direction:		Page No.:					
Veh Type	**Cars**	**33-seater bus**	**62-seater bus**	**10-Seater Matatus**	**14-seater matatus**	**33-seater bus**	**51-seater bus**
6:30 – 7:00	1.43	32.00	49.75	8.53	13.68	33.00	51.00
7:00 – 7:30	1.10	32.50	46.00	9.83	14.00	32.88	51.00
7:30 – 8:00	1.27	33.00	29.75	9.54	13.71	33.00	51.00
8:00– 8:30	1.30	18.00	35.50	8.31	14.00	32.85	51.00
8:30 – 9:00	1.30	2.00	24.00	9.67	13.95	33.00	42.00
9:00– 9:30	1.33	29.50	29.50	9.71	12.88	33.00	51.00
9:30 – 10:00	1.23	24.25	26.25	9.17	13.58	33.00	51.00
10:00– 10:30	1.33	14.50	23.50	10.08	13.69	33.00	51.00
10:30 – 11:00	1.39	19.00	8.00	9.67	13.38	33.00	51.46
11:00– 11:30	1.23	15.50	6.50	7.98	13.08	33.00	51.42
11:30 –12:00	1.37	11.25	8.00	10.29	12.39	32.33	51.25
12:00 – 12:30	1.48	15.50	3.50	10.00	13.07	32.55	52.22
12:30 – 1:00	1.60	18.00	6.00	9.96	12.14	32.02	51.15
1:00 – 1:30	1.42	21.50	24.00	10.38	12.25	32.77	51.82
1:30 – 2:00	1.52	12.00	21.00	9.33	13.35	33.74	48.39
2:00 – 2:30	1.53	22.00	19.00	10.00	12.75	33.89	48.14
2:30 – 3:00	1.60	17.50	37.00	9.07	12.33	47.45	51.41
3:00 – 3:30	1.28	11.00	12.00	8.80	12.56	31.60	51.95
3:30 – 4:00	1.28	2.50	12.25	8.79	12.76	31.73	52.05
4:00 – 4:30	1.49	2.00	48.50	9.46	12.32	26.94	51.95
4:30 – 5:00	1.40	17.50	27.00	9.10	11.81	32.32	51.36
5:00 – 5:30	1.54	16.33	18.33	8.90	12.43	32.10	51.99
5:30 – 6:00	1.52	27.00	41.50	8.63	12.65	30.57	50.32
6:00 – 6:30	1.47	11.00	19.00	8.88	12.96	43.60	51.10
Average	**1.39**	**17.72**	**23.99**	**9.33**	**12.99**	**33.47**	**50.71**

D3: Average Vehicle Occupancy along Ruaraka-Muthaiga Segment (3)

Vehicle Occupancy: Thika -		Observer:					
Location:		Weather:					
Station Number:		Date:					
Direction:		Page No.:					
Veh Type	**Cars**	**33-seater bus**	**62-seater bus**	**10-Seater Matatus**	**14-seater matatus**	**33-seater bus**	**51-seater bus**
6:30 – 7:00	1.64	26.88	30.30	9.04	14.08	31.82	51.00
7:00 – 7:30	1.46	35.25	26.75	9.15	14.00	31.52	52.09
7:30 – 8:00	1.57	39.50	34.50	9.25	13.79	29.83	51.92
8:00– 8:30	1.51	24.38	44.42	8.94	13.18	31.06	49.30
8:30 – 9:00	1.61	16.88	19.25	7.98	11.60	25.99	44.65
9:00– 9:30	1.46	30.25	22.50	9.71	11.99	27.15	45.00
9:30 – 10:00	1.54	19.13	44.13	9.16	9.73	26.86	41.30
10:00– 10:30	1.42	10.38	26.75	8.64	10.68	25.61	46.53
10:30 – 11:00	1.70	11.21	5.75	8.69	11.50	27.11	46.21
11:00– 11:30	1.38	13.46	7.50	8.10	11.71	23.19	41.40
11:30 –12:00	1.53	9.63	10.25	8.35	9.59	23.77	40.20
12:00 – 12:30	1.75	10.13	5.00	7.18	8.95	23.48	37.41
12:30 – 1:00	1.60	16.75	5.75	8.75	9.26	16.24	31.41
1:00 – 1:30	1.65	13.00	17.75	10.00	9.33	21.72	34.97
1:30 – 2:00	1.87	7.00	11.50	10.00	12.52	17.00	31.19
2:00 – 2:30	1.60	27.50	32.00	9.00	10.88	23.06	33.30
2:30 – 3:00	1.71	17.25	21.25	10.00	9.20	26.90	38.58
3:00 – 3:30	1.42	14.00	21.75	9.00	8.23	15.33	39.25
3:30 – 4:00	1.62	12.13	30.71	8.00	9.07	17.58	29.75
4:00 – 4:30	1.73	12.67	30.50	9.50	10.79	16.66	35.86
4:30 – 5:00	1.53	21.19	20.25	9.60	11.12	28.10	38.65
5:00 – 5:30	2.10	16.04	18.04	8.83	7.56	12.76	8.70
5:30 – 6:00	1.80	15.35	37.83	10.00	6.03	13.84	16.27
6:00 – 6:30	1.92	7.00	24.75	10.00	5.90	10.87	13.26
Average	**1.63**	**17.79**	**22.88**	**9.04**	**10.45**	**22.81**	**37.43**

D4: Average Vehicle Occupancy along Muthaiga-Pangani Segment (4)

Vehicle Occupancy: Thika -		Observer:					
Location:		Weather:					
Station Number:		Date:					
Direction:		Page No.:					
Veh Type	**Cars**	**33-seater bus**	**62-seater bus**	**10-Seater Matatus**	**14-seater matatus**	**33-seater bus**	**51-seater bus**
6:30 – 7:00	1.86	21.75	10.85	8.38	11.30	29.70	58.63
7:00 – 7:30	1.82	38.00	7.50	10.17	13.28	32.30	61.88
7:30 – 8:00	1.87	46.00	39.25	6.00	13.75	32.95	78.33
8:00– 8:30	1.71	30.75	53.34	7.94	13.33	32.45	58.45
8:30 – 9:00	1.91	31.75	14.50	9.53	13.80	32.65	56.76
9:00– 9:30	1.58	31.00	15.50	7.17	13.55	32.90	56.28
9:30 – 10:00	1.84	14.00	62.00	2.50	13.15	30.35	57.15
10:00– 10:30	1.50	6.25	30.00	8.60	13.60	30.69	56.45
10:30 – 11:00	2.01	3.42	3.50	9.38	13.85	30.50	60.40
11:00– 11:30	1.53	11.43	8.50	9.50	12.70	31.35	58.05
11:30 –12:00	1.69	8.00	12.50	9.38	12.99	49.48	56.85
12:00 – 12:30	2.03	4.75	6.50	6.50	11.60	31.84	56.27
12:30 – 1:00	1.60	15.50	5.50	6.33	12.58	44.55	52.75
1:00 – 1:30	1.88	4.50	11.50	9.00	12.05	30.15	52.97
1:30 – 2:00	2.22	2.00	2.00	8.75	11.70	37.35	52.75
2:00 – 2:30	1.68	33.00	45.00	7.00	12.05	31.35	51.95
2:30 – 3:00	1.82	17.00	5.50	8.08	12.20	30.95	47.80
3:00 – 3:30	1.55	17.00	31.50	7.50	11.70	30.85	44.00
3:30 – 4:00	1.95	21.75	49.17	6.90	11.95	29.85	49.60
4:00 – 4:30	1.97	23.33	12.50	7.58	11.90	29.40	52.85
4:30 – 5:00	1.67	24.88	13.50	6.83	11.02	28.55	46.19
5:00 – 5:30	2.65	15.75	17.75	6.50	12.30	28.90	45.55
5:30 – 6:00	2.07	3.70	34.17	4.00	10.95	26.20	38.10
6:00 – 6:30	2.38	3.00	30.50	5.00	10.15	22.45	63.35
Average	**1.87**	**17.85**	**21.77**	**7.44**	**12.39**	**31.99**	**54.72**

Appendix E: Established Hourly Passenger Loads

E1: Hourly Passenger Loads along Githurai-Roysambu Segment (1)

PASSENGER LOADS ALONG THE GITHURAI-ROYSAMBU SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	**10-14 seater Private van**	**62-seater private bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 7:30	3475	306	29	115	3816	2121	4768	**14630**
7:30 – 8:30	2358	783	97	146	3733	1917	4918	**13952**
8:30 – 9:30	2206	411	0	107	3808	2100	4273	**12904**
9:30 – 10:30	2207	793	0	108	3023	2402	4263	**12797**
10:30 – 11:30	1807	391	0	112	2613	2320	4071	**11314**
11:30 –12:30	1929	193	0	76	2870	2233	3493	**10793**
12:30 – 1:30	1346	842	51	133	2708	1325	2677	**9081**
1:30 – 2:30	1593	225	24	60	2850	1396	2666	**8815**
2:30 – 330	1506	263	0	105	2983	1040	2644	**8542**
3:30 – 4:30	2111	315	400	93	2736	882	3105	**9643**
4:30 – 5:30	3119	445	127	66	2814	1495	2630	**10696**
5:30 – 6:30	2940	408	18	34	3488	1507	2402	**10796**
Total	**26597**	**5375**	**745**	**1155**	**37442**	**20738**	**41911**	**133962**
Modal Split	**19.85%**	**4.01%**	**0.56%**	**0.86%**	**27.95%**	**15.48%**	**31.29%**	

E2: Hourly Passenger Loads along Roysambu-Ruaraka Segment (2)

PASSENGER LOADS ALONG THE ROYSAMBU-RUARAKA SEGMENT								
	PRIVATE TRANSPORT			**PUBLIC TRANSPORT**				
	Cars	**10-14 seater vans**	**62-seater bus**	**10-seater matatu**	**14-seater matatu**	**33-41-seater minibus**	**42-62-seater bus**	**Total**
6:30 – 7:30	2749	839	192	37	3599	4908	8007	**20329**
7:30 – 8:30	2527	867	131	214	2674	3556	6579	**16547**
8:30 – 9:30	2527	567	27	97	2858	4686	6092	**16853**
9:30 – 10:30	2686	1356	75	29	3055	5280	4641	**17121**
10:30 – 11:30	2219	1052	29	88	2156	3762	6842	**16148**
11:30 –12:30	2313	268	0	81	2495	3536	4604	**13297**
12:30 – 1:30	1898	948	90	81	2524	2883	3810	**12234**
1:30 – 2:30	2246	391	100	87	2976	3044	4151	**12994**
2:30 – 330	1845	413	25	54	3060	3636	4238	**13271**
3:30 – 4:30	1952	83	547	36	3485	3256	5252	**14612**
4:30 – 5:30	2622	575	227	99	3552	3865	6046	**16986**
5:30 – 6:30	1913	836	91	44	4097	5006	6389	**18376**
Total	27496	8195	1531	947	36530	47419	66651	**188769**
Modal Split	14.57%	4.34%	0.81%	0.50%	19.35%	25.12%	35.31%	

E3: Hourly Passenger Loads along Ruaraka-Muthaiga Segment (3)

PASSENGER LOADS ALONG THE RUARAKA-MUTHAIGA SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater vans	62-seater bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	4198	311	86	36	4365	10018	8164	**27178**
7:30 – 8:30	4662	32	197	218	5894	11666	11757	**34427**
8:30 – 9:30	2768	730	63	88	4093	7397	6238	**21378**
9:30 – 10:30	2620	664	0	27	3698	6658	5639	**19305**
10:30 – 11:30	2616	802	7	84	3368	6002	5251	**18129**
11:30 –12:30	2671	326	15	62	3127	5624	4236	**16061**
12:30 – 1:30	2463	893	24	75	3084	4221	4027	**14786**
1:30 – 2:30	2617	845	87	86	3187	4269	3143	**14234**
2:30 – 330	2536	719	65	57	3259	4333	3760	**14729**
3:30 – 4:30	2300	545	122	35	2935	3774	4638	**14349**
4:30 – 5:30	3229	614	96	101	4358	5415	4615	**18428**
5:30 – 6:30	2908	492	94	50	5586	7976	6091	**23197**
Total	**35588**	**6972**	**854**	**920**	**46954**	**77353**	**67558**	**236200**
Modal Split	**15.07%**	**2.95%**	**0.36%**	**0.39%**	**19.88%**	**32.75%**	**28.60%**	

E4: Hourly Passenger Loads along Muthaiga-Pangani Segment (4)

PASSENGER LOADS ALONG THE MUTHAIGA-PANGANI SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater vans	62-seater bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	9,191	1,583	73	111	3,772	7,564	9,218	**31,514**
7:30 – 8:30	7,373	3,377	324	153	6,499	11,412	11,489	**40,627**
8:30 – 9:30	6,273	1,600	75	50	3,815	4,687	11,756	**28,257**
9:30 – 10:30	4,564	608	138	22	4,240	3,510	5,680	**18,762**
10:30 – 11:30	4,075	557	24	47	4,553	4,762	9,239	**23,258**
11:30 –12:30	4,676	376	-	32	3,812	3,700	7,014	**19,609**
12:30 – 1:30	3,445	470	-	77	3,227	3,511	5,233	**15,962**
1:30 – 2:30	4,861	2,293	71	24	3,479	2,679	8,585	**21,992**
2:30 – 330	3,807	1,870	37	16	3,262	2,256	6,472	**17,719**
3:30 – 4:30	4,264	2,637	31	36	3,827	2,311	10,450	**23,556**
4:30 – 5:30	6,407	894	94	53	4,326	5,285	6,055	**23,114**
5:30 – 6:30	5,894	147	129	32	5,055	4,597	10,551	**26,405**
Total	**64,830**	**16,412**	**996**	**653**	**49,868**	**56,275**	**101,742**	**290,775**
Modal Split	**22.30%**	**5.64%**	**0.34%**	**0.22%**	**17.15%**	**19.35%**	**34.99%**	

Appendix F: Established Hourly Passenger-Kilometres Covered

F1: Hourly Passenger-km Covered along Githurai-Roysambu Segment (1)

PASSENGER-KM ALONG THE GITHURAI-ROYSAMBU SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater Private van	62-seater private bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	11120	980	94	367	12210	6788	15258	**46,817**
7:30 – 8:30	7545	2506	309	468	11944	6135	15739	**44,646**
8:30 – 9:30	7058	1316	0	342	12184	6720	13673	**41,292**
9:30 – 10:30	7062	2537	0	345	9675	7687	13643	**40,949**
10:30 – 11:30	5784	1251	0	358	8362	7424	13026	**36,206**
11:30 –12:30	6171	616	0	244	9185	7145	11176	**34,538**
12:30 – 1:30	4308	2694	163	426	8666	4238	8565	**29,060**
1:30 – 2:30	5098	721	75	192	9121	4467	8533	**28,207**
2:30 – 330	4820	840	0	337	9546	3329	8462	**27,333**
3:30 – 4:30	6756	1008	1279	297	8756	2823	9937	**30,857**
4:30 – 5:30	9980	1424	407	210	9005	4784	8417	**34,227**
5:30 – 6:30	9408	1306	57	109	11160	4823	7685	**34,548**
Total	**85109**	**17199**	**2383**	**3695**	**119815**	**66363**	**134115**	**428,680**
Modal Split	**19.9%**	**4.0%**	**0.6%**	**0.9%**	**27.9%**	**15.5%**	**31.3%**	

F2: Hourly Passenger-km Covered along Roysambu-Ruaraka Segment (2)

PASSENGER-KM ALONG THE ROYSAMBU-RUARAKA SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater Private van	62-seater private bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	10,445	3,186	728	140	13,675	18,652	30,427	**77,252**
7:30 – 8:30	9,602	3,295	496	814	10,161	13,512	25,000	**62,878**
8:30 – 9:30	9,601	2,155	102	368	10,859	17,807	23,148	**64,040**
9:30 – 10:30	10,206	5,154	284	110	11,608	20,064	17,636	**65,061**
10:30 – 11:30	8,432	3,999	110	335	8,194	14,296	25,998	**61,364**
11:30 –12:30	8,791	1,017	-	308	9,481	13,436	17,497	**50,530**
12:30 – 1:30	7,211	3,602	342	309	9,591	10,957	14,477	**46,489**
1:30 – 2:30	8,537	1,486	380	331	11,308	11,565	15,773	**49,379**
2:30 – 330	7,012	1,570	93	204	11,630	13,818	16,104	**50,431**
3:30 – 4:30	7,417	316	2,078	139	13,244	12,373	19,959	**55,525**
4:30 – 5:30	9,963	2,186	861	376	13,496	14,688	22,975	**64,545**
5:30 – 6:30	7,269	3,177	345	166	15,567	19,024	24,279	**69,828**
Total	**104,486**	**31,142**	**5,818**	**3,599**	**138,814**	**180,192**	**253,272**	**717,322**
Modal Split	**14.6%**	**4.3%**	**0.8%**	**0.5%**	**19.4%**	**25.1%**	**35.3%**	

F3: Hourly Passenger-km Covered along Ruaraka-Muthaiga Segment (3)

PASSENGER-KM ALONG THE RUARAKA-MUTHAIGA SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater Private van	62-seater private bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	13,855	1,025	282	120	14,406	33,058	26,940	**89,687**
7:30 – 8:30	15,385	105	651	720	19,452	38,498	38,799	**113,610**
8:30 – 9:30	9,134	2,410	207	292	13,507	24,410	20,587	**70,547**
9:30 – 10:30	8,646	2,190	-	88	12,203	21,971	18,608	**63,707**
10:30 – 11:30	8,633	2,646	22	277	11,113	19,808	17,328	**59,827**
11:30 –12:30	8,813	1,075	50	205	10,318	18,561	13,978	**53,000**
12:30 – 1:30	8,128	2,945	78	248	10,178	13,928	13,288	**48,793**
1:30 – 2:30	8,637	2,789	287	282	10,516	14,089	10,372	**46,972**
2:30 – 330	8,370	2,372	213	188	10,756	14,299	12,407	**48,605**
3:30 – 4:30	7,589	1,800	404	116	9,685	12,453	15,306	**47,351**
4:30 – 5:30	10,655	2,027	316	335	14,383	17,870	15,228	**60,813**
5:30 – 6:30	9,597	1,623	310	165	18,434	26,321	20,099	**76,549**
Total	**117,441**	**23,009**	**2,819**	**3,035**	**154,949**	**255,266**	**222,940**	**779,460**
Modal Split	**15.1%**	**3.0%**	**0.4%**	**0.4%**	**19.9%**	**32.7%**	**28.6%**	

F4: Hourly Passenger-km Covered along Muthaiga-Pangani Segment (4)

PASSENGER-KM ALONG THE MUTHAIGA-PANGANI SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater Private van	62-seater private bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	10,110	1,742	81	122	4,149	8,320	10,140	**34,665**
7:30 – 8:30	8,110	3,715	356	169	7,148	12,554	12,638	**44,690**
8:30 – 9:30	6,901	1,760	83	55	4,197	5,156	12,932	**31,083**
9:30 – 10:30	5,021	668	152	24	4,664	3,861	6,248	**20,638**
10:30 – 11:30	4,482	612	26	52	5,009	5,239	10,163	**25,583**
11:30 –12:30	5,144	414	-	35	4,193	4,070	7,715	**21,570**
12:30 – 1:30	3,789	517	-	84	3,550	3,862	5,757	**17,559**
1:30 – 2:30	5,348	2,522	78	26	3,827	2,947	9,444	**24,191**
2:30 – 330	4,188	2,057	41	17	3,589	2,481	7,119	**19,491**
3:30 – 4:30	4,690	2,901	34	40	4,210	2,542	11,495	**25,911**
4:30 – 5:30	7,048	983	103	59	4,759	5,814	6,660	**25,426**
5:30 – 6:30	6,483	162	142	35	5,560	5,057	11,606	**29,045**
Total	**71,313**	**18,053**	**1,095**	**718**	**54,855**	**61,902**	**111,917**	**319,853**
Modal Split	**22.3%**	**5.6%**	**0.3%**	**0.2%**	**17.1%**	**19.4%**	**35.0%**	

Appendix G: Established Hourly Car Seats Availed

G1: Car Seats Availed Hourly along Githurai-Roysambu Segment (1)

AVAILABLE CAR SEATS ALONG THE GITHURAI-ROYSAMBU SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater Private van	62-seater private bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	10,345	209	55	140	3,850	1,920	4,845	**21,364**
7:30 – 8:30	8,150	286	110	160	3,668	1,800	4,845	**19,019**
8:30 – 9:30	8,100	286	-	110	3,864	1,950	4,335	**18,645**
9:30 – 10:30	7,900	605	-	110	3,234	2,400	4,386	**18,635**
10:30 – 11:30	5,000	528	-	140	2,758	2,250	4,182	**14,858**
11:30 –12:30	5,300	154	-	80	2,926	1,890	3,723	**14,073**
12:30 – 1:30	4,300	407	110	140	2,940	1,260	2,805	**11,962**
1:30 – 2:30	4,500	187	55	60	3,052	1,350	3,315	**12,519**
2:30 – 330	4,150	231	-	110	3,318	1,110	3,468	**12,387**
3:30 – 4:30	6,150	308	715	140	3,290	960	5,151	**16,714**
4:30 – 5:30	7,650	275	385	100	3,192	1,560	3,672	**16,834**
5:30 – 6:30	7,150	374	55	40	4,186	1,770	5,712	**19,287**
Total	**78,695**	**3,850**	**1,485**	**1,330**	**40,278**	**20,220**	**50,439**	**196,297**
Modal Split	**40.09%**	**1.96%**	**0.76%**	**0.68%**	**20.52%**	**10.30%**	**25.70%**	

G2: Car Seats Availed Hourly along Roysambu-Ruaraka Segment (2)

AVAILABLE CAR SEATS ALONG THE ROYSAMBU-RUARAKA SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater vans	62-seater bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	10,850	286	220	40	3,640	4,470	8,007	**27,513**
7:30 – 8:30	9,815	374	220	240	2,702	3,240	6,579	**23,170**
8:30 – 9:30	9,595	396	55	100	2,982	4,260	6,681	**24,069**
9:30 – 10:30	10,490	770	165	30	3,136	4,800	4,641	**24,032**
10:30 – 11:30	8,500	671	220	100	2,282	3,420	6,783	**21,976**
11:30 –12:30	8,135	220	-	80	2,744	3,270	4,539	**18,988**
12:30 – 1:30	6,280	528	330	80	2,898	2,670	3,774	**16,560**
1:30 – 2:30	7,380	253	275	90	3,192	2,700	4,386	**18,276**
2:30 – 330	6,395	319	55	60	3,444	2,760	4,182	**17,215**
3:30 – 4:30	7,040	407	990	40	3,892	3,330	5,151	**20,850**
4:30 – 5:30	8,920	374	550	110	4,102	3,600	5,967	**23,623**
5:30 – 6:30	6,385	484	165	50	4,480	4,050	6,426	**22,040**
Total	**99,785**	**5,082**	**3,245**	**1,020**	**39,494**	**42,570**	**67,116**	**258,312**
Modal split	**38.63%**	**1.97%**	**1.26%**	**0.39%**	**15.29%**	**16.48%**	**25.98%**	

G3: Car Seats Availed Hourly along Ruaraka-Muthaiga Segment (3)

AVAILABLE CAR SEATS ALONG THE RUARAKA-MUTHAIGA SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater vans	62-seater bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	13,525	110	165	40	4,788	9,060	7,650	**35,338**
7:30 – 8:30	15,155	11	275	240	6,160	10,290	10,251	**42,382**
8:30 – 9:30	9,045	341	165	100	4,326	6,510	6,324	**26,811**
9:30 – 10:30	8,875	495	-	30	3,920	6,060	5,457	**24,837**
10:30 – 11:30	8,500	715	55	100	3,640	5,430	4,947	**23,387**
11:30 –12:30	8,130	363	110	80	3,584	4,470	4,080	**20,817**
12:30 – 1:30	7,575	660	110	80	3,612	3,510	4,029	**19,576**
1:30 – 2:30	7,535	539	220	90	3,668	3,630	3,264	**18,946**
2:30 – 330	8,105	506	165	60	3,836	3,570	4,029	**20,271**
3:30 – 4:30	6,870	484	220	40	3,444	3,690	4,692	**19,440**
4:30 – 5:30	8,895	363	275	110	5,264	5,130	4,947	**24,984**
5:30 – 6:30	7,820	484	165	50	6,874	7,500	6,273	**29,166**
Total	**110030**	**5071**	**1925**	**1020**	**53116**	**68850**	**65943**	**305955**
Modal Split	**35.96%**	**1.66%**	**0.63%**	**0.33%**	**17.36%**	**22.50%**	**21.55%**	

G4: Car Seats Availed Hourly along Muthaiga-Pangani Segment (4)

AVAILABLE CAR SEATS ALONG THE RUARAKA-MUTHAIGA SEGMENT								
	PRIVATE TRANSPORT			PUBLIC TRANSPORT				
	Cars	10-14 seater vans	62-seater bus	10-seater matatu	14-seater matatu	33-41-seater minibus	42-62-seater bus	Total
6:30 – 7:30	25,010	583	440	120	4,298	7,320	7,803	**45,574**
7:30 – 8:30	20,605	968	385	220	6,720	10,470	8,568	**47,936**
8:30 – 9:30	17,990	561	275	60	3,906	4,290	10,608	**37,690**
9:30 – 10:30	13,650	660	165	40	4,438	3,450	5,100	**27,503**
10:30 – 11:30	11,495	825	220	50	4,802	4,620	7,956	**29,968**
11:30 –12:30	12,550	649	-	40	4,340	2,730	6,324	**26,633**
12:30 – 1:30	9,895	517	-	100	3,668	2,820	5,049	**22,049**
1:30 – 2:30	12,455	1,441	165	30	4,102	2,340	8,364	**28,897**
2:30 – 330	11,285	1,210	110	20	3,822	2,190	7,191	**25,828**
3:30 – 4:30	10,870	1,287	55	50	4,494	2,340	10,404	**29,500**
4:30 – 5:30	14,830	484	330	80	5,194	5,520	6,732	**33,170**
5:30 – 6:30	**13,270**	**484**	**220**	**70**	**6,706**	**5,670**	**10,608**	**37,028**
Total	**173,905**	**9,669**	**2,365**	**880**	**56,490**	**53,760**	**94,707**	**391,776**
Modal Split	**44.39%**	**2.47%**	**0.60%**	**0.22%**	**14.42%**	**13.72%**	**24.17%**	

Appendix H: Spot Speeds for all the Sampled Vehicles

SPOT SPEEDS FOR SAMPLED VEHICLES

S.No	Passenger Cars	10-seaters	14-seaters	26-seaters	33-seaters	51-seaters	62-seaters
	Speed km/h	Speed km/h	Speed km/h	Speed km/h	Speed km/h	Speed km/h	Speed km/h
1	81.7	81.8	75.3	75.0	81.4	71.1	60.0
2	97.2	60.6	98.4	60.2	60.2	85.7	55.4
3	66.5	76.3	78.6	71.4	72.6	81.1	105.9
4	51.9	88.7	76.9	77.6	61.2	67.9	68.7
5	84.2	74.7	74.4	78.6	68.7	79.3	61.4
6	96.7	62.1	75.3	77.6	78.3	70.9	70.0
7	93.8	82.2	57.5		57.0	59.8	82.2
8	88.5	80.7	81.4		70.6	77.6	
9	79.3	65.9	75.9		61.0	67.2	
10	93.8	66.9	74.1		60.4	59.2	
11	89.4	75.9	61.4		62.9	61.6	
12	96.7	55.4	70.6		73.5	84.5	
13	102.4	75.3	102.3		86.1	59.6	
14	81.0	59.6	77.6		85.7	77.3	
15	88.1	87.8	59.2		90.5	63.6	
16	90.2	64.7	109.1		125.0	71.7	
17	92.0	84.5	73.5		52.0	105.9	
18	85.3	92.3	91.8		55.9	92.3	
19	106.4	67.7	62.3		51.6	73.5	
20	89.8	101.1	75.0		65.2	65.9	
21	82.7	59.6	75.3		62.1	59.0	
22	69.9	61.4	70.0		72.3	70.0	
23	60.7	97.8	72.3		73.8	98.9	
24	72.0	80.7	85.3		64.3	73.8	
25	59.2	86.5	74.4		65.2	71.4	
26	89.4	72.3	82.9		61.6	71.1	
27	121.5		82.9		83.3	72.0	
28	96.7		66.4		64.3	84.5	
29	77.3		89.6		60.2	71.7	
30	93.8		62.7		70.3	75.9	
31	85.7		75.0		67.7	66.2	
32	67.7		82.6		73.5	72.6	

33	74.9	88.7	73.2	64.1
34	55.4	88.2	75.9	82.6
35	121.5	91.4		95.2
36	78.0	83.7		64.3
37	107.7	76.6		83.3
38	81.0	87.4		70.3
39	88.1	90.5		69.5
40	81.0	77.3		81.4
41	89.4	89.6		74.4
42	83.1	72.6		89.1
43	69.9			73.8
44	91.5			68.7
45	92.4			70.3
46	93.3			70.0
47	61.1			75.0
48	71.2			76.3
49	86.9			86.5
50	88.5			
51	27.3			
52	78.9			
53	104.7			
54	88.5			
55	100.8			
56	83.1			
57	93.3			
58	91.1			
59	94.3			
60	108.3			
61	121.5			
62	73.4			
63	105.3			
64	73.2			
65	87.3			
66	92.9			
67	85.7			
68	72.6			
69	82.4			
70	77.0			

71	86.9						
72	77.0						
73	94.7						
74	77.3						
75	50.4						
76	85.7						
77	95.2						
78	85.0						
79	103.5						
80	73.2						
81	85.3						
82	130.7						
83	90.2						
84	88.5						
85	77.0						
86	90.2						
87	119.2						
88	134.3						
89	92.0						
90	71.2						
91	87.3						
92	78.9						
93	93.8						
94	79.9						
95	83.1						
96	124.7						
Average	**86.9**	**75.5**	**79.0**	**73.4**	**70.2**	**74.6**	**71.9**