UNIVERSITY OF NAIROBI

Department of Civil and Construction Engineering

Evaluation of Pedestrian Walkways along Urban Roads: The Case of Komarock, Nairobi

By

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F56/66871/2013

A thesis submitted to the School of Engineering of the University of Nairobi in partial fulfillment for the award of The Degree of Master of Science in Civil Engineering (Transportation Engineering)

April, 2018

DECLARATION

I hereby declare that this thesis is my original work. To the best of my knowledge, the work presented here has not been submitted for a degree in any other institution of higher learning.

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DEDICATION

This thesis is dedicated to my loving parents, Dr. Patrick Anyango Orege and Dr. (Mrs.) Isabella Anyango Orege, for the sacrifices they made towards my education.

ACKNOWLEDGEMENT

I am sincerely grateful to all those who have contributed towards the completion of my thesis. Special gratitude is directed to my supervisors, Prof. O. O. Mbeche and Prof. F. J. Gichaga for their tireless input, guidance and unending support throughout the process of conceptualization, developing and writing of this thesis.

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To all who are unmentioned, yet not overlooked or underestimated, God bless you abundantly.

ABSTRACT

Walkways facilitate movement of people, and in this thesis a sidewalk includes any type of dedicated passage for pedestrian oriented activities. Even with pedestrians constituting a large proportion of trip makers along Nairobi's urban areas, the current practices of the local authorities underestimate the importance of walking. The urban roads and streets in a high density, mixed-use development area, have been designed taking into consideration the requirements of vehicular growth and neglecting pedestrian's needs. In cases where facilities are provided, they are either encroached by hawkers or physically obstructed by parked vehicles. Consequently, pedestrians are forced to use the road carriageway, hence increasing their frictions and making them vulnerable. In order to determine how well pedestrian walkways accommodate pedestrian movement, or how safe it is crossing the road, this study assesses the walking conditions in Nairobi's Eastlands area. It evaluates the level of service of the pedestrian walkways along urban roads in *Komarock*, based primarily on space, speed, and density, and includes safety as a potential performance element. This study revealed that the pedestrian walkway width in *Komarock* Area varies from between 0 meters to 2 meters and as such cannot accommodate the high pedestrian densities during peak morning and evening hours. This lead to the pedestrians competing with motorised transport for movement space thereby causing conflict. The study recommends redesign of the pedestrian walkway along *Kayole* Junction to the recommended 2.0m width, which can also accommodate disabled movement, installation of raised pedestrian crossing humps along *Kayole* Junction, *Masimba* and Mama Lucy Junction to reduce vehicular speeds, installation of raised kerbs and 1.0m high railings along the entire study area to allow for the segregation of motorised and non-motorised transport and demolition of structures occupying part of the walkway width and enforcement of laws regarding encroachment, in order to keep the pedestrian walkways free from encumbrances. The findings of this study are compared with the planning, design and operation guidelines for pedestrian facilities and recommendations made in research studies from developed countries in an attempt to enhance pedestrian environments in Kenya.

Key words: *Pedestrian Flow Characteristics, Pedestrian Level of Service, Pedestrian Space, Pedestrian Speed, Pedestrian Density, Pedestrian Walkways*

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ACRONYMS

AC	Asphalt Concrete
ADA	Americans with Disabilities Act
CASA	Centre for Advanced Spatial Analysis
CBD	Central Business District
CEQR	City Environmental Quality Review
EU	European Union
Ft	Feet
GDP	Gross Domestic Product
GM	General Manager
HCM	Highway Capacity Manual
ITE	Institute of Transportation Engineers
ITF	International Transport Federation
LOS	Level of Service
KeNHA	Kenya National Highways Authority
KNBS	Kenya National Bureau of Statistics
KRB	Kenya Roads Board
KURA	Kenya Urban Roads Authority
MOLHUD	Ministry of Lands, Housing & Urban Development
MOW	Ministry of Works
MRA	Multiple Regression Analysis
NCC	Nairobi City County
NMA	Nairobi Metropolitan Area
NMT	Non-Motorized Transport
NUSG	Nairobi Urban Study Group
NYC	New York City
OCS	Officer Commanding Station
PLOS	Pedestrian Level of Service
RTIs	Road Traffic Injuries
R/A	Roundabout
SQM	Square Meters
TRAVL	Trip Rate Assessment Valid for London
UN	United Nations
US/USA	United States of America
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Despite being the most fundamental form of mobility, walking remains the most neglected transport mode, and the circulation systems have been designed or redesigned to serve those who drive. In Kenya, as is the case in most other developing countries, a significant proportion of the population walk on a daily basis to their places of work, and to other destinations. This underscores the need for the planning and design of safe and comfortable walking facilities, whose width is typically governed by the pedestrian volume.

With the increase in population and motor vehicles, pedestrian facilities separate pedestrian traffic from vehicular flow, thereby increasing the perceived safety. The services delivered by these facilities, however, need to be evaluated to further enhance the pedestrian environment, and increase opportunities to choose walking as a viable transportation mode. This can be effectively carried out through the evaluation of the offered level of service (LOS), a concept that was first developed by traffic engineers for vehicular capacity studies connected with street and highway design.

Although the Highway Capacity Manual (HCM) 2010 provides guidelines for designing walkways using the LOS concept, these standards were developed for traffic conditions in developed countries, the application of which may not be a true reflection of the existing conditions in Kenya. Using the quantitative measures of space, density and speed, this thesis identifies the challenges experienced by pedestrians on walkways, especially along urban roads. In addition, it is essential, that qualitative elements, such as attractiveness, comfort, convenience, security, and safety, be taken into consideration (HCM, 2010). Notably, the combined effects of the quantitative and qualitative performance measures contribute to the level of service of a particular facility.

This study evaluates the design of the pedestrian facilities along urban roads in *Komarock* and includes parameters such as PLOS, pedestrian walking speed and density, and recommends on local design standards that can be adopted to enhance pedestrian safety as they go about their daily activities. As a potential performance measure, safety in this thesis includes the ease of movement in walking, even in vehicle-free areas such as sidewalks and passageways (HCM, 2010). Particularly in heavily trafficked street networks such as *Komarock*, the provision of properly designed control devices, providing adequate time and space separation from vehicular movement is an essential part of safety.

1.2 STUDY AREA CHARACTERISTICS

Komarock Ward is a middle-class and low-income residential area, situated 18 Kilometers East of Nairobi Central Business District (CBD), popularly known as "Eastlands." According to a survey, the Ward itself has a population of 35,628, with a density of about 22,267 persons per square Kilometer of developed land (Kenya Population and Housing Census, 2009). Simultaneously, studies reveal that the population of Nairobi alone has reached about 3.2 million (2009); this development has not been met with commensurate growth in urban transport infrastructure and services (Integrated National Transport Policy (INTP), 2012). Figure 1-1 below illustrates the population growth trend within the City of Nairobi.

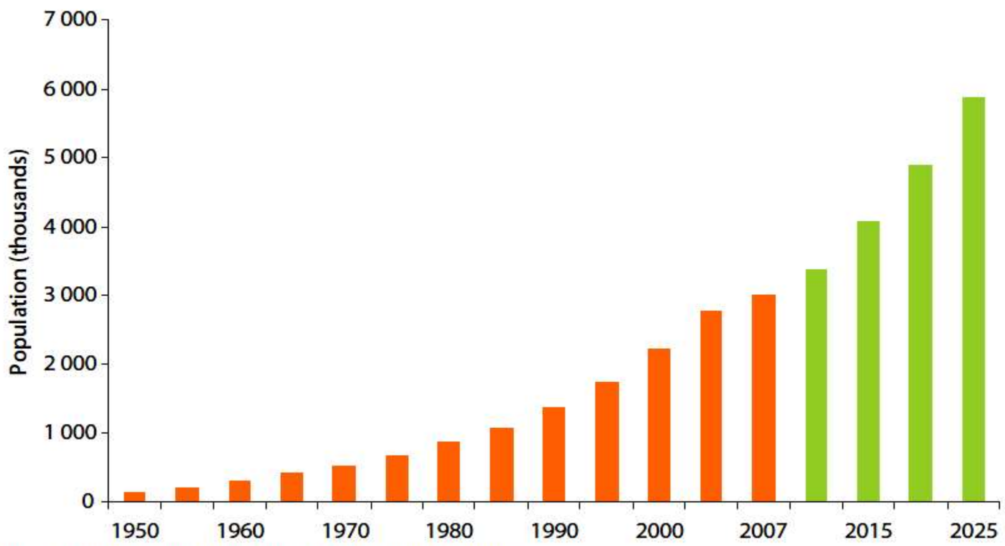


Figure 1-1: Nairobi's Historical and Projected Population

Source: KNBS, 2008

1.2.1 Land Use Patterns and Transportation

Local land use patterns within the study area are predominantly residential, including other land uses such as commercial, schools, hospitals, light industrial, recreation and public purpose. Further, buses, '*matatus*[*]', taxis, motorcycles and non-motorized vehicles provide urban passenger transport in Komarock and its environs. Several bus bays where passengers board and alight from public and private transport are also found within the study area. Due to lack of proper transportation facilities within the area, public transport vehicles pick up and drop passengers along the road.

[*]*matatu - a minibus, minivan or similar vehicle used as a taxi or in public transport in Kenya.*

1.2.2 Choice of Study Area

Komarock was selected as the pilot study due to the high volume of pedestrian activity generated by the middle and low-income housing dwellers, most of whom either walk along the study area to and from industrial area. This raises the demand for a pedestrian-friendly facility network, which is well integrated with urban land use and transport planning mechanisms for Nairobi and its environs. The pilot roads along the study area conform to the Gridiron pattern and include: *Kangundo* Road (3.5 Kilometers long), *Kayole* Spine (5.1 Kilometers long) and *Kangaru* Road (2.6 kilometers long) and are classified as urban arterial, collector and local streets respectively.

Kangundo Road

Kangundo Road is a bituminous single carriageway, which starts at Mama Lucy Hospital Junction and ends at the *Kayole* Spine Road Junction at Bridge International School – *Matopeni* (See Figure 1-2 below).

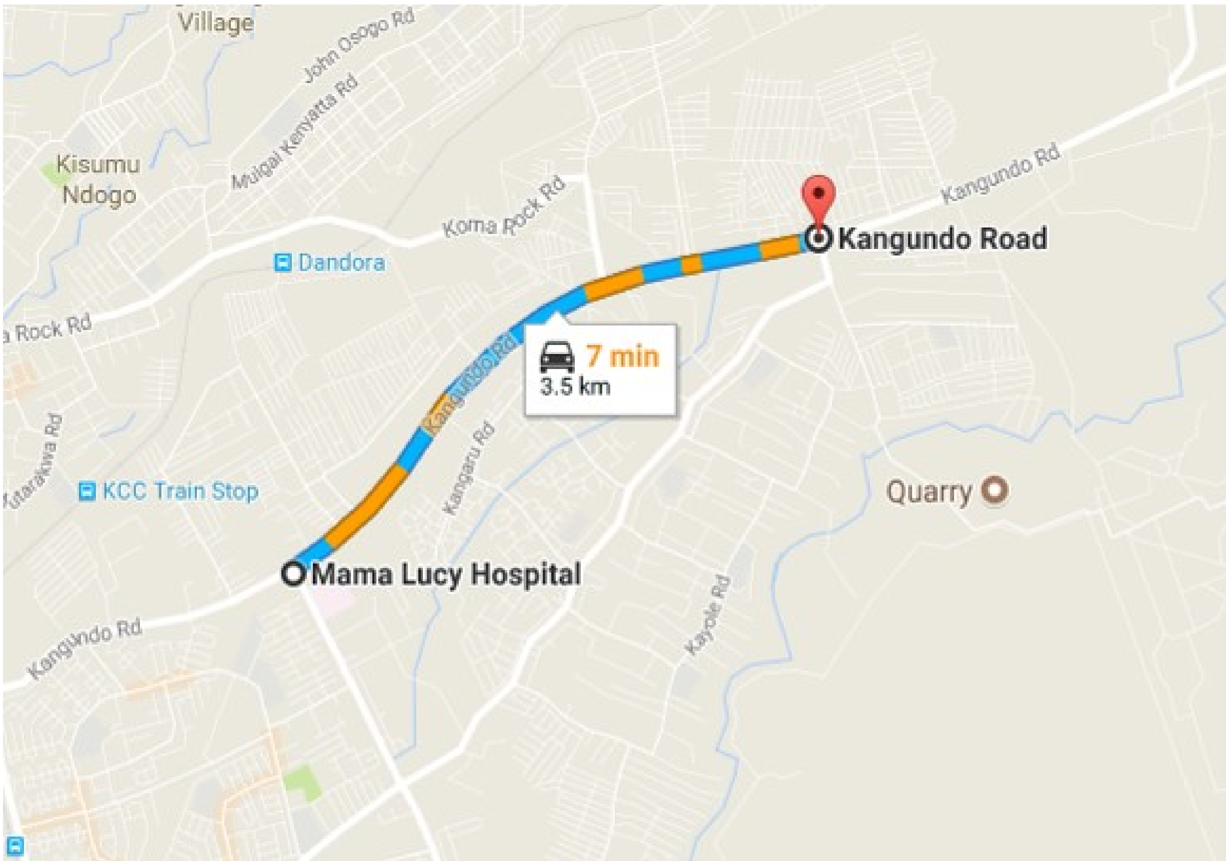


Figure 1-2: Kangundo Road Section and its Environs

Source: Google Maps, 2015

Kayole Spine Road Section

Kayole Spine Road section is classified as a Collector Street as is connects urban arterials, such as *Kangundo* Road. It also receives traffic from local streets and estate roads within the area. Mama Lucy Hospital is also adjacent to the road section (See Figure 1-3 below).

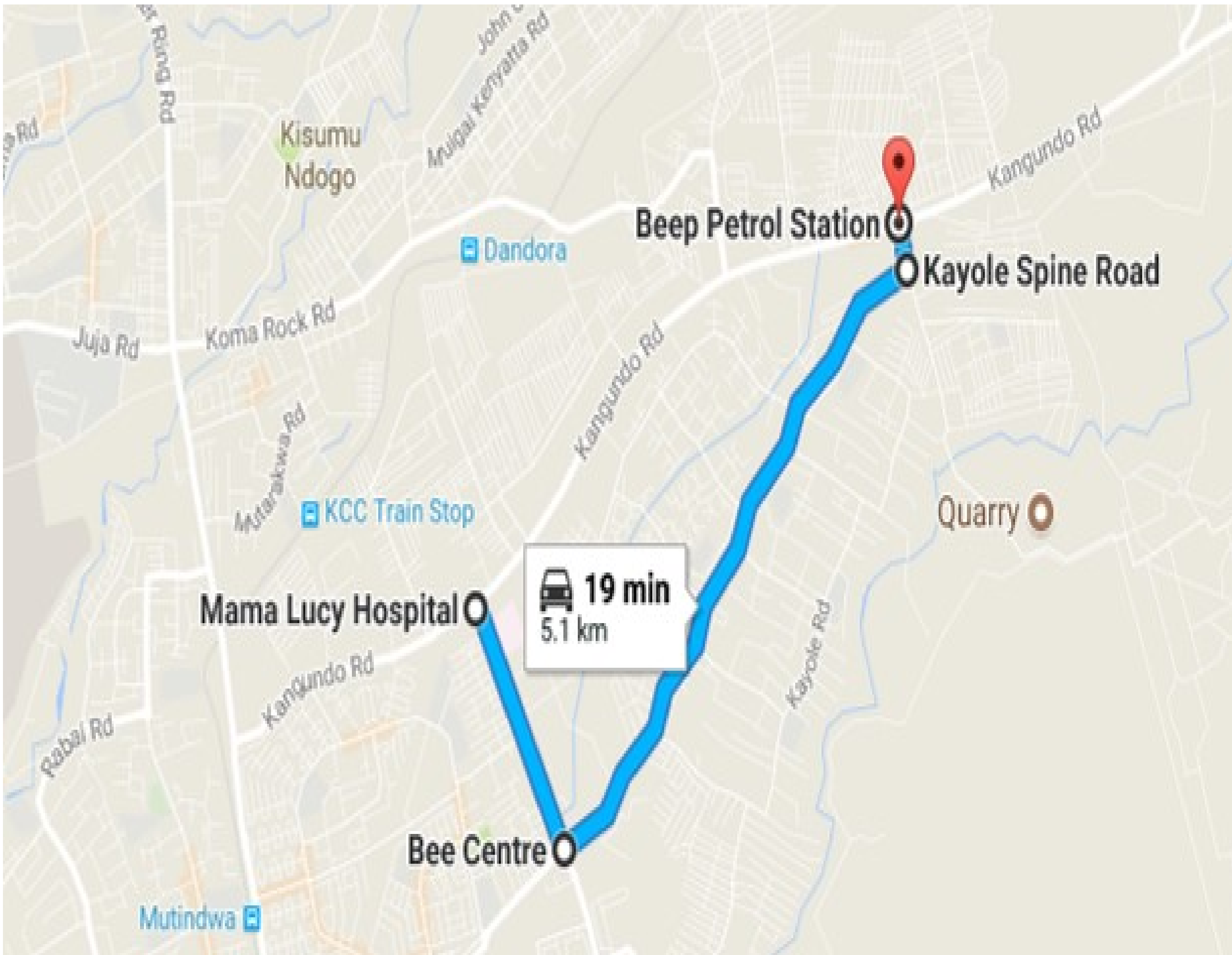


Figure 1-3: Kayole Spine Road Section and its Environs

Source: Google Maps, 2015

Kangaru Road Section

Kangaru Road is a bituminized single carriageway, which starts at the junction with *Kayole* Spine Road at Calvary Bus Stop and is classified as a local street as it receives traffic from estate roads and directs them towards the main collector street - *Kayole Spine* Road (See Figure 1-4).

Figure 1-4: Kangaru Road Section and its Environs.

Source: Google Maps, 2015

1.3 PROBLEM STATEMENT

As a means of transportation, walking constitutes the primary means of internal movement within urban areas. According to research, walking made 64 % of all trips originating from Nairobi's Eastlands area along the *Jogoo* Road corridor, and terminating in industrial area and the Central Business District (De Langen and R. Tembele, 2001). These densely packed street networks; combined with the assemblages of pedestrians that navigate them especially during peak hours, create corridors for pedestrian crashes. This warrants a comprehensive analysis of walking characteristics of pedestrians, including an assessment of the adequacy of pedestrian facilities along the urban roads in *Komarock*.

Despite being paved, however, pedestrian walkways along *Komarock* are riddled with irregular shoulders and blocked drains, and typically remain of poor quality. Currently, a significant proportion of the walkway facilities are inadequate, with widths varying from between 0m to 1.5m depending on the location. Further observations elucidate encroachment by hawkers and vendors, and parking of vehicles on sidewalks. Inevitably, pedestrians are forced to walk on a portion of the carriageway, thus increasing their interaction with vehicles and putting them at greater risk. There is lack of integration of pedestrian transport facilities with other transport modes and land use, and that affects the optimal use of the existing facilities in the study area. Proper planning and design of pedestrian facilities can improve the performance of public transport termini, and deter the offloading of passengers on major routes along the study area, due to engineering shortcomings.

With the rise in Nairobi's population, the Eastlands area continues to expand. Consequently, *Komarock* experiences a large accretion of people from various parts of the city and outskirts throughout the day. These frequent pedestrian interactions cause a reduction of walking speed and further compromise the level of service provided to the people.

1.4 RESEARCH QUESTIONS

i. Are there challenges facing pedestrians as they walk along the study area?

ii. Are the current pedestrian space, flow and density conditions on the walkways along the study area adequate?

iii. Are there ways that can address the design shortfalls of pedestrian facilities along the study area?

1.5 STUDY OBJECTIVES

The study has the following specific objectives:

i. To establish the challenges facing pedestrians along the study area;

ii. To determine the adequacy of the pedestrian space, flow and density conditions on the walkways;

iii. To establish ways of addressing the design shortfalls of pedestrian facilities along the study area.

1.6 SCOPE OF THE STUDY

The study has been limited to the major classes of urban roads within *Komarock* including urban arterials, collector streets and local streets. These roads traverse areas of mixed land use (both commercial and residential), which are used by a high number of pedestrians, private cars, non-motorized transport and public transport. It is assumed that the investigations and findings from this study may be replicated on similar roads within Nairobi City County.

1.5 LIMITATIONS OF THE STUDY

This study focuses on the pedestrian flow characteristics along walkways in *Komarock* Area, and is limited by the following scope:

i. Calculation of the capacity and pedestrian level of service (PLOS) of the walkways.

ii. Pedestrian flows on walkways along Kangundo Road, Kayole Spine Road and Kangaru Road within Komarock Area.

iii. Pedestrian's personal characteristics (age, gender and presence of luggage), behaviour characteristics (trip purpose, origin and destination) and pedestrian travel characteristics (flow, volumes, travel time, average speeds and densities).

The study does not include other aspects of pedestrian movement such as: shared walkway facilities, effect of bi-directional flow on pedestrian characteristics, effect of variation in weather on pedestrian flow, signalised pedestrian intersections and pedestrian flows on other pedestrian facilities such as footbridges and stairs. Multiple linear regression is the only model that has been used in the analysis, other models such as category analysis and travel demand models by use of household surveys have not been considered for this study.

1.7 JUSTIFICATION OF THE STUDY

Pedestrian capacity analysis is a relatively new area of study, beginning with Fruin's Pedestrian Planning and Design in 1971. In recent years, however, various researchers have proposed a number of theories and models related to pedestrian flow characteristics on different amenities. Nevertheless, most of these ideas were advanced in the United States of America, Europe and other developed countries. In the Kenyan context, efforts towards developing service criteria of pedestrian facilities are yet to bear fruition. Consequently, this study attempts to plug into the knowledge gap in transportation planning and engineering research by contributing towards the methodologies proposed to evaluate pedestrian level of service. As Kenya strives to make itself an economic powerhouse within Africa, providing safe and comfortable pedestrian facilities for the growing populous, is an important goal for the government. Thus, it is imperative to evaluate the local pedestrian flow characteristics and establish standards for improving the design of pedestrian walkways along the country's urban roads.

CHAPTER TWO: LITERATURE REVIEW

This chapter reviews and compares studies on pedestrian movement on urban roads carried out globally and in Kenya. It highlights the theories that various authors have established on pedestrian flow characteristics on walkways, providing an overview of the various factors that affect pedestrian's behaviour and the pedestrian's Level of Service (LOS). It outlines the main models for evaluating the efficiency and suitability of pedestrian walkways, which are important in the context of this study.

2.1 PLANNING FOR PEDESTRIAN MOVEMENT

Transportation planning for pedestrians ensures that the mobility requirements for pedestrians are supplied and maintained at acceptable levels, to help achieve economic, social and environmental opportunity objectives. It is a complex process because of the numerous factors that interact with each other, within a pedestrian transportation system. For example, when designing for pedestrian transportation systems on land, all factors that affect both vehicular and non-vehicular transport on the roadway must be taken into account for the design to be considered a success (Paquette, 1982).

Designing for pedestrian facilities can either be long-term or short-term. The latter are far less complex and require minimal designs or construction, for example, the installation of median barriers across roads to prevent unauthorised pedestrian crossing at Haile Selassie Road within Nairobi's CBD. Long-term or strategic planning on the other hand involves policy making, huge financial implications and extensive construction activities, such as the ongoing rehabilitation of Ngong Road in Nairobi. Nonetheless, long-term planning is generally the most preferred approach due to the attention to detail and complex nature of problems to be solved (Paquette, 1982).

According to several authors, there are three basic elements that constitute any long-term transportation planning process (Ashford et al, 1975) namely:

i. Forecasting of demand for the system at the various levels of facility provision being considered;

ii. Description of economic, social and environmental changes that will accompany the development of the system at these same levels of facility provision;

iii. An evaluation of the system in terms of the benefits and dis-benefits accruing from the various options considered.

2.1.1 Pedestrian Walkways on Urban Roads

Like in other parts of the world, the majority of pedestrians in Kenya walk along the walkways or road shoulders, which form part of the existing road network. Often these facilities are either paved or unpaved, or may lack other amenities such as bus bays, pedestrian footbridges, hand rails, raised footpaths or signage. According to the Kenya Road Design Manual (1979), urban roads in Kenya are classified into three main categories: urban arterials, which join the main CBD; collector streets, which carry both pedestrian and vehicular traffic to the estates; and local streets, which allow for pedestrian movement within the estates.

In Kenya, urban roads form primary grids of surface roadways and boundaries of commercial zones or residential areas. As with highways, high speeds and volumes of arterials create barriers for pedestrians where there are long distances between junctions or designated crossing points. Most are single carriageways (with few being dual carriageways) with pedestrian crossings at junctions. Still, evidence exists of pedestrians crossing at grade or uncontrolled midblock locations, and using medians as refuge spaces or crossing at designated junctions. However, informal breaks and vandalism still allows pedestrians to cross. This situation is further exacerbated by pedestrians crossing at uncontrolled locations due to long distances between signalized junctions, or the inconvenience of having to use footbridges.

Collectors and local roads are designed to provide access to residential areas such as neighbourhoods. Most have one lane in each direction and provide for the lowest speeds and volumes, including the highest levels of accessibility to adjacent land uses. As incremental development demands, high levels of traffic volumes overburden the few collector and local roads. Consequently, pedestrians are forced onto the carriageway, due to lack of shoulders and designated walkways.

2.2 PEDESTRIAN TRIP GENERATION

G. M. Lamb (1970), defines trip generation within transportation planning as the process of calculating the number of trip ends in a given area. It aims to understand the reasons behind the trip making behaviour, and produces mathematical relationships to understand the trip-making pattern on the basis of observed trips, land use data and household characteristics. According to

Shuldiner (1962), trips are typically divided into home-based trips and non-home-based trips with the former having one end of the trip at the home of persons making the trip, whilst the latter includes trips that have neither end at home of the person making the trip.

2.2.1 Factors Governing Pedestrian Trip Generation

Kassoff (1969) conducted several trip generation studies and came up with several factors that affect and influence pedestrian movement from one area to another. Where '*n*' = more than one family member is employed or goes to school, more trips will be realised as compared to those family units where none is employed or goes to school.

- Land use characteristics: High density residential areas such as apartments attract and produce more trips when compared to low density areas with stand-alone houses in their own compounds. Low-income areas such as slums produce more pedestrian trips due to the high number of people living there as compared to affluent areas where there is high reliance on private cars;

- Distance of zone from town centre: The further the town centre, the less the number of trips to be made by a family unit and vice versa.

- Accessibility to public transport and its efficiency: The more efficient the public transport is, the more the number of trips will be generated due to the ease of access of the public transport system and vice versa,

- Employment opportunities: The areas with more employment opportunities such as industries or shopping centres, generate more trips when compared to areas without or areas with few offices, shops or malls.

2.2.2 Pedestrian Trip Generation Models

Pedestrian trip generation models help to analyse and predict the number of pedestrians generated from different land uses. The models make it possible to forecast changes to the pedestrian flow and the crowding scenario for different changes to the urban network. Whereas vehicular trip generation approaches have been used since the 1950s, several transportation studies have established that non-motorised trip generation is still uncommon, and few models have been designed (Pantzar M., 2012). The following are some of the models adopted by several cities worldwide.

Multiple Linear Regression Analysis

Multiple linear regression is a statistical tool for fitting mathematical relationships between dependent and independent variables. In the case of trip generation equations, the dependent variable is the number of trips, while the independent variables are the various measurable factors that influence trip generation. G. M. McCarthy (1969), provides the following equation:

$$Y_p = a_1X_1 + a_2X_2 + a_3X_3 + \ldots\ldots + a_nX_n + U$$

Where	Y_p	=	*number of trips for specified purpose p*
	$X_1, X_2, X_3 \ldots X_n$	=	*independent variables*
	$a_1, a_2, a_3 \ldots a_n$	=	*coefficients of independent variables*
	U	=	*disturbance constant*

The following assumptions need to be considered:

i. That all the variables are independent of each other;

ii. That all the variables are normally distributed;

iii. That all variables are continuous;

iv. That a linear relationship exists between independent and dependent variables; and

v. That the influence of independent variable is additive (i.e. the inclusion of each variable in the equation contributes towards a distinct portion of trip numbers).

The strengths and weaknesses of the multiple linear regression model are as shown in the Table 2-1 below:

Table 2–1: Strengths and Weaknesses of Multiple Linear Regression Analysis

Strengths of Multiple Linear Regression	Weaknesses of Multiple Linear Regression
It gives a better prediction from multiple predictors	Multiple linear regression is often inappropriately used to model non-linear relationships.
It avoids depending on a single predictor as there are several variables	Multiple linear regression is limited to predicting numeric output
It avoids use of non-optimal combinations of predictors (e.g., total scores)	Possible for regression model to exhibit high R^2 but low predictive accuracy
It creates a relationship between the predictors	Multiple linear regression only looks at a

Strengths of Multiple Linear Regression	**Weaknesses of Multiple Linear Regression**
and the criterion – multi-causal relationships	relationship between the mean of the dependent variable and the independent variables.
Multiple regression models allow the examination of more sophisticated research hypotheses than is possible using simple correlations	Multiple linear regression is sensitive to outliers which can either be data that is univariate (based on one variable) or multivariate (based on many variables).
It gives a "link" among the various correlation and analysis of variance models.	Multiple linear regression assumes that all the data is independent and as such numerous independent variables may be obtained.

Source: Kadiyali, 1987

City of London Methodology

According to Lumley (2012) the City of London Methodology framework is based on a first principles approach which involves certain assumptions about land use with specific reference to commercial developments in London. Where employee trips are involved, the following assumptions are made:

i. The gross area occupied per employee is 16 square meters

ii. All offices have a daily occupancy rate of 85% (including employees on leave or those who are sick)

iii. 43% of employees arrive in the office during the morning peak

iv. 33% of employees depart from the office during the evening peak.

However, where visitors are involved, the following assumptions are made:

i. A daily visitor trip rate of 1 visitor per 36.50 square meters is applied

ii. 2% of visitors arrive at the office during the morning peak

iii. 5% of visitors arrive at the office during the evening but only 8% depart during this period

A tool called Trip Rate Assessment Valid for London (TRAVL) calculates the trip generation rates with each calculation being determined by the nature of the development. TRAVL predicts trip rates and the modal split of new developments based on survey information of comparable sites throughout London. It gives an indication as to whether predicted trip rates are realistic, but since TRAVL is based on averages, estimates are only as good as the data put into the software (Lumley R., 2012).

Centre for Advanced Spatial Analysis (CASA) Method, University College London

The Centre for Advanced Spatial Analysis at University College London set up a pedestrian demand methodology in 2003. It describes a pedestrian demand model that provides predicted flow values for different city streets. The model has been ‘independently validated by Transport for London and is being tested against further observation data’ (Desyllas J. et al., 2003). The authors’ approach was to ‘focus on the development of a flexible and testable pedestrian modelling framework using Multiple Regression Analysis (MRA)’ (Desyllas J. et al., 2003). The model tests the following components: (i) capacity (pavement width); (ii) land use (office, retail); (iii) street grid configuration in terms of visibility and accessibility; and (iv) transport accessibility (tube station entry). In this method, pavement width analysis is made from average effective footway width in meters per street segment, where, red is the highest average pavement width and blue is the lowest. The visibility analysis highlights the ‘difference between 'desire lines' or important visual links through the street grid and the more secluded back streets’, and the accessibility by neighbourhoods accessible within ‘two steps away’ (Desyllas J. et al., 2003).

Institute of Transportation Engineers (ITE) Trip Generation (New York City, USA)

The US national system of trip generation analysis includes multimodal transportation such as pedestrian trips. The system conducts trip generation rates for different transport modes in different settings, and cities can use the data as templates when they lack access or ability to get empirical figures (Rizavi A., and Yeung A., 2010; Institute of Transportation Engineers, 2015).

2.3 PEDESTRIAN FLOW CHARACTERISTICS STUDIES

Older (1968), carried out pedestrian flow characteristic studies on walkways in and around shopping areas on Central London in the United Kingdom. His studies focused on speed – flow relationships of shoppers along walkways adjacent to malls and shopping centres. Earlier studies carried out by Oeding (1963) in Germany established various speed-flow relationships for different types of pedestrians for example shoppers and pedestrians going to work exhibited different speed-flow relations. Studies carried out by Pushkarev and Zupan (1975), and Fruin (1971) focused on pedestrian flow characteristics for commuters in New York and established that pedestrians with different trip purposes exhibit different flow characteristics with specific reference to pedestrian speed, pedestrian flow and density. Years later, Morall et al (1991), carried out a comparative study of the pedestrian characteristics between Asian countries and Canada, and deduced that the techniques for pedestrians planning for Asian countries should be specific to these countries and Western pedestrian design standards should not be adopted. A similar study was conducted by Tanaboriboob (1991), who concurred with this view.

A study carried out by Daly et al (1991), to determine the travel time functions for various pedestrian facilities gave the most comprehensive results for speed-flow relationships in stations within the United Kingdom. Similarly, Widjajanti (1997), in his studies of pedestrian characteristics for Jakarta, Indonesia established a speed-flow relationship based on the Greenshield model, where he observed that men's walking speed was greater than women's. He concluded that the LOS for sidewalks was defined based on the pedestrian LOS concept given in the Highway Capacity Manual, 2010.

Sahani (2012) carried out a study on the development of the LOS criteria of urban walking environment in India where he explained the LOS criteria for urban off-streets pedestrian facilities using the *K-means clustering technique*. Pedestrian space, flow rate, speed and volume to capacity (v/c) ratio were considered in the classification of LOS categories of the off-street pedestrian facilities. His findings revealed that the LOS categories A, B, C, D, E and F had different ranges of the four defined parameters. Good LOS was observed in categories A, B and C as opposed to poor LOS in D, E and F. It is worth noting that the LOS defined by Sahani (2012) differs from those in the HCM (2010) because of irregular and inconsistent pedestrian walkway widths, obstructions along the pedestrian walkway, lack of enforcement of traffic rules and illegal parking by vehicular traffic on pedestrian facilities.

A study on the pedestrian flow characteristics at Vadodara railway in *Gujarat*, India carried out by Shaha et al (2013) investigated pedestrian movement characteristics 15 minutes before and after the arrival of trains. The factors considered during this study, included time of day, gender, and age. Of the 3,411 pedestrians sampled by means of videos, it was noted that pedestrians walk faster in the afternoon as compared to the evening and those with luggage walk slower as opposed to those without any luggage. This was attributed to the additional weight of the luggage and complexity of carrying it from one place to the other.

2.3.1 Pedestrian Studies in Kenya

The Nairobi Metropolitan Growth Strategy (1973) developed by the Nairobi Urban Study Group (NUSG) predicted that the population of Nairobi is likely to increase from its 1973 level of under

700,000 people to between 2,880,000 and 4,200,000 by the end of the Century and approximately 750,000 jobs would be available in Nairobi at the end of the century in both the modern and informal sectors, leading to approximately 250,000 potential wage earners looking for work, and unable to find it. The NUSG also observed that the number of cars owned in the Nairobi City is likely to increase tenfold over the next thirty years if no measures of restraint are adopted. Under these conditions, the number of roads and car parks needed would rise proportionately, and the associated costs would increase even more sharply. NUSG recommended that the Kenya Government and City Council of Nairobi adopt the recommended strategy as the basis for the future expansion and development of the city, including development of additional car parks, stoppage of free parking and increases in car parking fees, improved traffic controls, including provision for pedestrian safety and 2m wide pedestrian walkways. (NUSG, 1973)

A study carried out by Ngegea, S. (1996) on planning for pedestrian mode of travel between *Kibera's* residential zone and Industrial Area in Nairobi, Kenya looked at the functional qualities of the pedestrians with a view of determining proposals towards improving their movement. This study however, did not examine the pedestrian flow characteristics and as such no local design parameters were obtained. A similar study by Onyiro, G. (1977) established that there were several conflicts between pedestrians and motor vehicles within the Nairobi CBD.

Kasuku (2001) carried out a study on provision of pedestrian transport facilities in Nairobi with specific reference to the Jogoo Road Corridor. The study recognized the role played by pedestrian mode of transport in the functioning of various urban activities such as industrial production. It emphasized that the poor provision of pedestrian facilities in urban areas, was due to various factors such as: increased and rapid urban population growth, coupled with high level of urban poverty; the lack of urban services; poor urban management and unrealistic transport planning. As a solution towards the identified pedestrian problems, the study recommended spatial planning proposals such as: the design of footbridges and footpaths; provision of security and safety measures; and the use of planning methodology to provide for pedestrian transport facilities.

A paper published by Mbeche, O. et al in 2001 sought to establish the appropriate design criteria for pedestrian movement on crossings and to assess pedestrian traffic requirements at the selected junction crossings. This study established the necessary local pedestrian flow parameters and compared them to those established by Fruin (1971), with a recommendation that the proposed local design values be adopted for design of pedestrian facilities within Nairobi City. When compared to other studies undertaken in cities elsewhere, the study revealed that most pedestrians walk during the day rather than at night. From the study, the maximum pedestrian flow obtained was 79 peds/min/m, which was lower than Fruin's recommended maximum value of 81 peds/min/m. Similarly, the average pedestrian speeds were 1.11 m/s on crosswalk widths, and were lower than the 1.34 m/sec recommended by Fruin (1971). For pedestrian space, an area of $0.30m^2$ was obtained per pedestrian, a figure lower than Fruin's (1971) recommended value of $0.46m^2$ per pedestrian.

A study conducted by the United Nations Environmental Programme (UNEP) and Kenya Urban Roads Authority (KURA) along UN Avenue in Nairobi in 2009, established that the lack of safe facilities for pedestrians and cyclists had led to several fatal accidents within the area. To improve the situation, several countermeasures such as the construction of 3m wide raised pedestrian walkways on either side of the road, construction of slip lanes for left turning vehicles and separation of motorised and non-motorised traffic were proposed, designed and implemented during the rehabilitation of the UN Avenue (See Plate 2-1 to Plate 2-4 below)

Plate 2-1: UN Avenue before rehabilitation

Source; UNEP, 2010

Plate 2-2: UN Avenue after rehabilitation

Source; UNEP, 2010

Plate 2-3: Kerb ramps used to increase usability for all including the disabled

Source; UNEP, 2010

Plate 2-4: Raised pedestrian crosswalks at key crossing points

Source; UNEP, 2010

Mitullah et al (2012) conducted a study on the institutional challenges faced by Kenyan Authorities when planning for non-motorized transport. Notably, this study is more of a policy approach into how various authorities with interest in the road sector can have an integrated approach towards accommodating non-motorized transport on urban roads.

Ogendi et al (2013) conducted a study to determine the pattern of pedestrian injuries within the City of Nairobi and its implications on urban safety planning. Data was obtained from road traffic injury admissions to Kenyatta National Hospital (KNH). From the analysis, the authors realized that 59.1% of road traffic injury admissions were pedestrians. Similarly, approximately 39.4% were the leading category of motorized vehicles that were involved in collisions with pedestrians; and close to 70% of pedestrians surveyed were involved in accidents while crossing the road. The study recommended various measures to improve pedestrian safety within the City of Nairobi such as provision of pedestrian walkways, introduction of vehicle speed calming measures in area with high pedestrian populations and enforcement of traffic laws amongst others.

Manyanja A. (2013) carried out a study on non-usage of pedestrian footbridges in Kenya where he examined the *Uthiru* pedestrian footbridge along Nairobi's Waiyaki Way. The study utilized pedestrian level of service along the footbridge to establish design parameters that could be used to design pedestrian movement facilities. Further, it established that the existing footbridge width of 2.2m was inadequate and recommended 5.0m.

2.4 LEGISLATIONS GOVERNING PEDESTRIAN FLOW AND SAFETY IN KENYA

Urban roads are arguably the most important public spaces in cities, and pedestrians are its largest users. Still, quite a number of urban roads in Kenya lack footpaths or designated pedestrian walking areas. According to statistics obtained from the Kenya Police (2010), in the last few years, pedestrian fatalities have accounted for 47% of all road accident deaths in urban areas in Kenya. With an increasing number of motor vehicles and diminishing pedestrian spaces, there is an urgent need to ensure the protection and rights of pedestrians. The government of Kenya has put in place several legislations that safeguard pedestrian rights directly and indirectly namely:

i. The Traffic Act Chapter 403, Laws of Kenya

ii. Public Road and Roads Access Act Cap 399

iii. Street Adoption Act Cap 406

iv. Physical Planning Act No. 6 of 1996.

2.4.1 The Traffic Act Chapter 403, Laws of Kenya

Effective from January 1, 1954, and amended in 2015, this Act consolidates laws, rules and regulations relating to road traffic and covers, inter alia: registration and licensing of vehicles including public service vehicles; issue of driving license; regulation of traffic; parking; accidents; suspension; cancellation and endorsement of driving licenses; general provisions regarding inspection; detention of vehicles and traffic offences. Nonetheless, evidence suggests that the Traffic Act Chapter 403 has not been able to regulate road traffic effectively. This is because the Kenya Police, responsible for prosecuting the offenders under this Act, are neither properly equipped, nor have the requisite infrastructure to carry out the mandate. Further, the courts are overwhelmed with a heavy backlog of traffic related cases. Public service vehicles are the worst offenders and cause a large number of road traffic fatalities.

In this scenario, the need for strict enforcement of the rules and regulations with firm emphasis on motorized and non-motorized passenger safety requirements cannot be overemphasized. The National Road Safety Council, mandated with the responsibility for road safety coordination and management, requires strengthening for vigorous discharge of its functions. Induction of additional personnel as well as equipment for logistic support for Kenya Police including CCTVs, walkie-talkie sets, patrol vans, digital cameras among others. would be helpful in this regard. Other associated infrastructural facilities would also need to be strengthened to expedite disposal of traffic related cases. This Act gives a lot of emphasis on motorized transport and does not address any aspect of pedestrian routes, facilities, movement or safety.

2.4.2 Public Road and Roads Access Act Cap 399

The Public Road and Roads Access Act Cap 399 is an Act of Parliament to provide roads of public travel and access to public roads. It deals with dedication of line of public travel, applications to construct roads of access, notices to be served on landowners affected where access roads are to be constructed, granting of leave to construct road of access, right of way over roads of access and prohibition of classes of traffic. It does not address any aspect of pedestrian routes, facilities, movement or safety.

2.4.3 Street Adoption Act Cap 406

The Street Adoption Act Cap 406 applies to all Municipalities and County Councils established under the Local Government Act. Under the Act, a street means a highway, bridge, road, lane, footway or passage to any land reserved within the area of a local authority, and used as a means of access to two or more premises or areas of land, whether the public have a right of way over it or not. It also includes all channels, ditches, drains, sidewalks and culverts. The Minister in charge of Roads may declare any area or part thereof as adopted under the Act to the Local Authority. It does not specify any standards for pedestrian facilities.

2.4.4 Physical Planning Act No. 6 of 1998

Commencing on 29th October 1998, the Physical Planning Act No.6 provides for preparation and implementation of physical development plans. The Director of Physical Planning formulates national, regional and local physical developments, frames policies and guidelines and advises the Commissioner of Lands and the Local Authorities on appropriate land use patterns. The Act establishes Physical Planning Liaison Committees, the National Liaison Committee and lays down their functions, procedures and provision for appeals. Local Authorities are allowed to control, approve and regulate development projects subject to environmental impact assessment, as well as ensure preservation of buildings of special architectural value or artistic interest.

2.5 SUMMARY OF LITERATURE REVIEW

Overall, this literature review was conducted by going through similar studies carried out within Kenya, Africa and certain developed countries such as New Zealand, United Kingdom, Netherlands and United States of America. A wide range of recommendations was highlighted. Several of these models have been adopted in the latter chapters of this study for the analysis of the investigations conducted. A summary of the literature review listing identified strengths and weaknesses from the various authors are as shown in Table 2-5:

Table 2–2: Summary of Literature Review

Design Manual/ Guidelines				
	Author, Year	**Area of Study**	**Strengths**	**Comments**
1.	Ministry of Works, Roads Department, 1979.	Geometric Design of Rural Roads in Kenya	-Guidelines on rural road geometric design	-No design criteria for non-motorized transport facilities such as bicycles and pedestrians -Manual is outdated and needs to be revised.
2.	Ministry of Local Government & Carl Bro. & Partners (Kenya Urban Transport Infrastructure Project), 2001.	Road Design Guidelines for Urban Roads	-Guidelines on urban roads geometric design	-No basis for design of non-motorized transport facilities such as footpaths and cycle tracks -Manual still in the draft stage, is outdated and needs to be reviewed
3	Highway Capacity Manual (2010).	Pedestrian Mode, Pedestrian Characteristics	-Relationship between flow, speed and density -Pedestrian Level of Service	-Comprehensive pedestrian flow characteristics studies carried out in the USA from researchers such as Fruin and Pushkarev.
4	Fruin J. J. (1971); Fruin J. J. (1987).	Pedestrian planning and design	-Comprehensive study on principles of pedestrian flow	-Very few studies had been undertaken to establish pedestrian traffic models, as a result, Fruin applied vehicular Level of Service measurement to pedestrian flows and levels of crowding
5	Ministry of Roads, 2009.	-Draft Design Manual for Roads and Bridges -Draft Traffic Surveys Manual	-Updated guidelines on rural and urban road geometric design -Guidelines on traffic surveys for motorized and non-motorized traffic	-Manual still at draft stage and may still be subject to future revisions. As such, flow parameters may change in future.
Previous Studies in Other Countries				
	Author, Year	**Area of Study**	**Strengths**	**Comments**
1.	Older (1968); Fruin (1971); Oeding (1963); Pushkarev and Zupan (1975).	Movement of pedestrians on walkways in urban streets.	-Different categories of pedestrians exhibit different speed – flow relationships	-Models comparing speed – flow relationships among different groups of pedestrians were developed.
2	Morall et al (1991); Tanaboriboob et al (1991).	Pedestrian characteristics in Asian countries	-Design criteria for pedestrian facilities specific to Asian countries were developed.	-Different groups of pedestrians with various trip purposes exhibit different flow characteristics.
3	Daly et al (1991).	Time taken by pedestrians to travel along pedestrian facilities in underground stations	-Speed-flow relationship for pedestrians at underground stations were developed	-Study was conducted in underground stations only. Scenario for above ground stations was not developed.

Previous Studies in Other Countries				
	Author, Year	**Area of Study**	**Strengths**	**Comments**
4	Shaha et al (2013).	Pedestrian flow in scenario in Vadodara Railway Station, India.	-Pedestrian speed varies with time of day and presence of luggage -The larger the pedestrian flow, the larger the space required. For instance, 50ped/min/m required $0.45m^2$/ped as opposed to Fruin's results, whereby 60ped/min/m required $0.26m^2$/ped	- Presence of a large number of pedestrians carrying oversized luggage resulted in more space required per pedestrian as compared to the values recommended by Fruin.
5	Widjajanti E. (1997).	Pedestrian flow characteristics for Jakarta's Pedestrians	The Greenshield model used was validated; under uninterrupted flow conditions, speed and density are linearly related.	-Modelling movement/ travel time not done -Underwood's model and Greenberg's model could have been used to compare with the Greenshield model.
6	Sahani (2012).	Level of Service criteria for urban walkways.	-Pedestrian level of service values obtained was significantly different from those recommended in the HCM (2010) and was specific to the Indian scenario. -Pedestrian movement was influenced by irregular and inconsistent pedestrian walkway widths, obstructions along the pedestrian walkway, lack of enforcement of traffic rules and illegal parking by vehicular traffic on pedestrian facilities.	- This study is conducted for the city of *Bhubaneswar* and *Rourkela*, India. The population in these two cities was less than a million, for which pedestrian movement was comparatively lower than the highly populated metropolitan cities. The results may therefore not be applied in a scenario with considerably higher population such as Nairobi City with approximately 3.2 million people. -Only off-street pedestrian facilities were considered in data collection.
Previous Studies in Kenya				
	Author, Year	**Area of Study**	**Strengths**	**Comments**
1.	Ogendi et al (2013).	Pattern of Pedestrian Injuries in the City of Nairobi: Implications for Urban Safety Planning	-Pedestrian accident studies in Nairobi.	-Focused only on road trauma cases admitted to KNH.
2.	Mitullah et al (2012).	Mainstreaming Non-Motorised Transport (NMT) In Policy and Planning in Nairobi: Institutional Issues and Challenges	-Studies on NMT including institutional issues, policy challenges, design challenges and solutions to these problems.	-Qualitative study. No information on pedestrian characteristics developed.

Previous Studies in Kenya				
	Author, Year	**Area of Study**	**Strengths**	**Comments**
3	Kasuku S. (2001).	Pedestrian transport facilities along *Jogoo* Road in Nairobi, Kenya.	-Assessed the provision of pedestrian transport facilities within Jogoo corridor -Assessed the utilization levels of existing pedestrian transport facilities within Jogoo corridor	-Qualitative study on facilities/supply for pedestrian movement.
4	Mbeche O. et al (2001).	Design criteria for pedestrian crossings in Central Business District (CBD) of Nairobi (Paper).	-Established local criteria design standards for pedestrian movement at crossings and junctions	-Maximum pedestrian flow rate of 79ped/min/m lower than Fruin (1970)'s maximum value of 81ped/min/m -Average pedestrian walking speeds of 1.11m/s lower than Fruin (1970)'s average speeds of 1.34m/s
5	Manjanja A. (2013)	Non-usage of pedestrian footbridges in Kenya. The Case of *Uthiru* Pedestrian Footbridge on *Waiyaki* Way	-Local design standards for pedestrian footbridges was established. -Effective footbridge width of 2.2m is inadequate.	-The study was specific to overcrossings such as footbridges and cannot be replicated to at grade pedestrian walkways.
6	Onyiro G. (1977)	Pedestrian movement within Nairobi CBD	-Highlighted conflicts, dangers and possible solutions to pedestrian movement within Nairobi CBD	-Qualitative study that did not determine pedestrian flow parameters.
7	Ngegea (1996)	Pedestrian travel in *Kibera* and industrial area in Nairobi, Kenya	-Solutions to enhance pedestrian movement -Role played by pedestrian movement in urban transportation	-Qualitative study on pedestrian movement. -Pedestrian space, speed, density, PLOS and travel time not studied.
Models				
	Model	**Description and Variables**	**Strengths**	**Comments**
1	Multiple Linear Regression Analysis (McCarthy, G. M., 1969)	$Y_p = a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n + U$, *Where* Y_p = *number of trips for specified purpose p* $X_1, X_2, \ldots X_n$ = *independent variables* a_1, a_2, a_n = *coefficients of independent variables* *U = disturbance constant*	-The model can be used to predict mathematical relationships between dependent and independent variables.	-The results obtained may be inaccurate given the number of independent variables.

Source: Author, November, 2015

2.6 MODEL ADAPTATION

This section gives an overview of the potential suitability of models that can be implemented in the analysis of pedestrian flow and in evaluating the performance of pedestrian walkways within *Komarock* Area. It identifies the base model requirements, which include the use of pedestrian traffic data to calibrate travel time functions, thus defining the pedestrian flow parameters, capacity and LOS of the pedestrian facilities. It culminates with the adoption of the travel time-based models by HCM (2010), which are capable of assessing the LOS that is provided to the pedestrians

2.6.1 Characteristics of Pedestrian Flow

There are basic variables, namely: volume (flow rate), speed, and density, which can be used to describe traffic on any roadway. In this study, volume or pedestrian traffic flow is a parameter common to both uninterrupted- and interrupted-flow facilities, but speed and density applies primarily to uninterrupted flow. Some parameters related to flow rate, such as spacing and headway, also are used for both types of facilities; other parameters, such as saturation flow or gap, are specific to interrupted flow.

Volume and Flow Rate

Volume and flow rate are two measures that quantify the number of pedestrians passing a point on a lane or roadway during a given time interval. These terms are defined as follows:

- Volume is the total number of pedestrians that pass over a given point or section of a lane or roadway during a given time interval. They can be expressed in terms of annual, daily, hourly, or sub hourly periods.

- Flow rate is the equivalent hourly rate at which pedestrians pass over a given point or section of a lane or roadway during a given time interval of less than 1 h, usually 15 min.

Volume and flow are variables that quantify demand, that is, the number of pedestrians who desire to use a given facility during a specific time period. Congestion can influence demand, and observed volumes sometimes reflect capacity constraints rather than true demand. The distinction between volume and flow rate is important. On the one hand, volume represents the number of pedestrians observed or predicted to pass a point during a time interval, whilst flow rate represents the number of pedestrians passing a point during a time interval less than 1 hour, but expressed as an equivalent hourly rate. Similarly, a flow rate is defined by the number of pedestrians observed in a sub hourly period, divided by the time (in hours) of the observation. Peak flow rates and hourly volumes produce the peak-hour factor (PHF), the ratio of total hourly volume to the peak flow rate within the hour, computed by Equation 2-1 below (HCM, 2010):

$$PHF = \frac{\text{Hourly volume}}{\text{Peak flow rate (within the hour)}}$$

Equation 2-1

If 15-min periods are used, the PHF may be computed by Equation 2-2 below (HCM, 2010):

$$PHF = \frac{V}{4 \times V_{15}}$$

Equation 2-2

Where PHF = peak-hour factor

V = hourly volume (ped/h)

V_{15} = volume during the peak 15 min of the peak hour (ped/15 min).

When the PHF is known, it can convert a peak-hour volume to a peak flow rate, as in Equation 2-3 below (HCM, 2010):

$$v = \frac{V}{PHF}$$

Equation 2-3

Where v = flow rate for a peak 15-min period (ped/h)

V = peak-hour volume (ped/h)

PHF = peak-hour factor.

Equation 2-3 does not need to be used to estimate peak flow rates if pedestrian counts are available; however, the chosen count interval must identify the maximum 15-min flow period. The rate then can be computed directly as 4 times the maximum 15-min count (HCM, 2010).

Speed

Although pedestrian traffic volumes provide a method of quantifying capacity values, speed (or its reciprocal of travel time) is an important measure of the quality of the traffic service provided to the pedestrian. It is an important measure of effectiveness defining levels of service for many types of facilities, walkways and urban streets.

Speed is defined as a rate of motion expressed as distance per unit of time, generally as meters per second (m/s). In characterizing the speed of a traffic stream, a representative value must be used, because a broad distribution of individual speeds is observable in the traffic stream. In this study, average travel speed is used as the speed measure because it is easily computed from observation of individual vehicles within the traffic stream and is the most statistically relevant measure in relationships with other variables. Average travel speed is computed by dividing the length of the highway, street section, walkway or segment under consideration by the average travel time of the pedestrians traversing it. If travel times t_1, t_2, t_3, t_n (in hours) are measured for n pedestrians traversing a segment of length L, the average travel speed is computed using Equation 2-4 below (HCM, 2010).

$$S = \frac{nL}{\sum_{i=1}^{n} t_i} = \frac{L}{\frac{1}{n}\sum_{i=1}^{n} t_i} = \frac{L}{t_a}$$

Equation 2-4

Where S = average travel speed (m/s)

L = length of the highway segment (m)

t_i = travel time for the i^{th} vehicle to traverse the section (s)

n = number of travel times observed

$t_a = \frac{1}{n}\sum_{i=1}^{n} t_i$ = average travel time over L (s)

Density

Density is the number of pedestrians occupying a given length of a lane or roadway at a particular instant. For the computations in this study, density is averaged over time and is usually expressed as pedestrians per meter (ped/m). Direct measurement of density in the field is difficult, requiring a vantage point for photographing, videotaping, or observing significant lengths of walkways. Density can be computed, however, from the average travel speed and flow rate, which are measured more easily. Equation 2-5 is used for under saturated traffic conditions (HCM, 2010).

$$D = v/S \qquad \textit{Equation 2-5}$$

Where D = density (ped/m)

v = flow rate (ped/hr.)

S = average travel speed (m/s)

Density is a critical parameter for uninterrupted-flow facilities because it characterizes the quality of traffic operations. It describes the proximity of pedestrians to one another and reflects the freedom to manoeuvre within the traffic stream. Walkway occupancy is frequently used as a surrogate for density in control systems because it is easier to measure. Occupancy in space is the proportion of walkway length covered by pedestrians, and occupancy in time identifies the proportion of time a roadway cross section is occupied by pedestrians.

2.6.2 Relationship between Volume, Speed and Density Parameters

Equation 2-5 cites the basic relationship among the three parameters, describing an uninterrupted traffic stream. Although the equation $v = S * D$ algebraically allows for a given flow rate to occur in an infinite number of combinations of speed and density, there are additional relationships restricting the variety of flow conditions at a location. Figure 2-4 below shows a generalized representation of these relationships, which are the basis for the capacity analysis of uninterrupted-flow facilities. The flow-density function is placed directly below the speed-density relationship because of their common horizontal scales, and the speed-flow function is placed next to the speed-density relationship because of their common vertical scales. Speed is space mean speed.

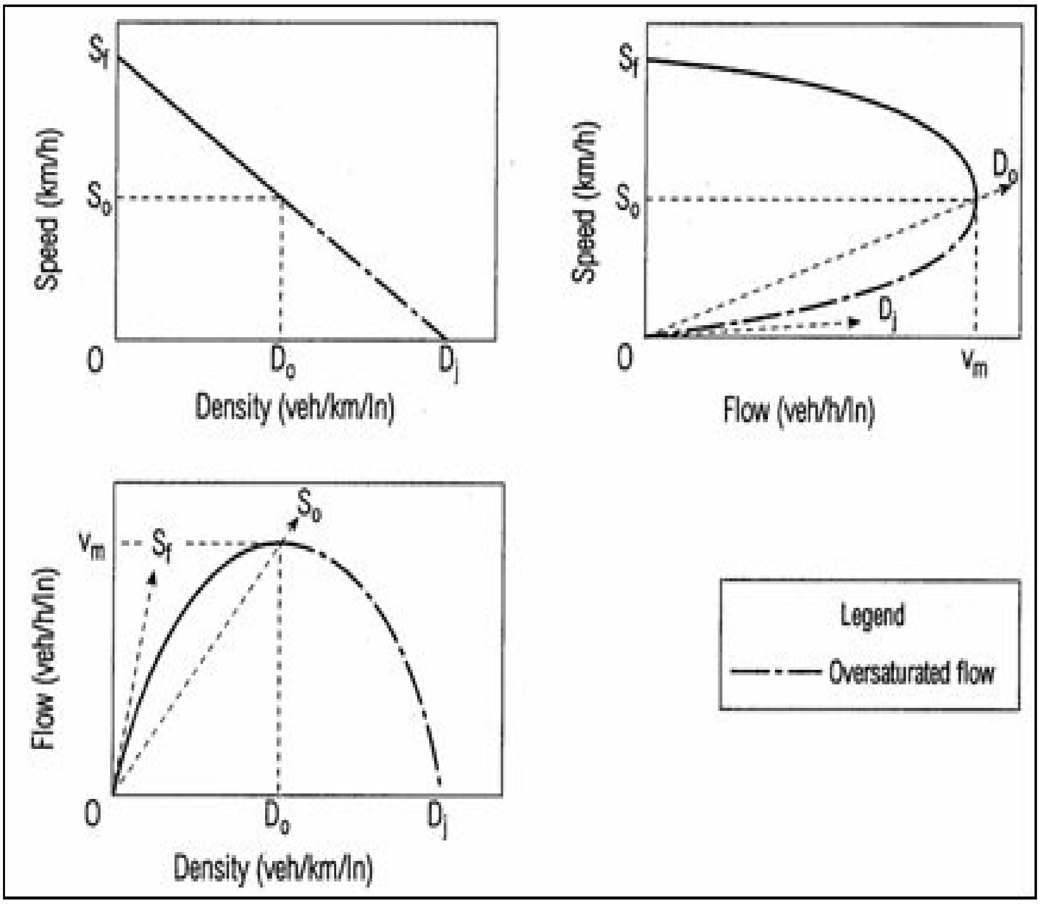


Figure 2–1: Generalized Relationships among Speed, Density, and Flow Rate on Uninterrupted-Flow Facilities

Sources: May, 1990 and HCM, 2010

The form of these functions depends on the prevailing traffic and roadway conditions on the segment under study and on its length in determining density. Although the diagrams in Figure 2-4 show continuous curves, it is unlikely that the full range of the functions would appear at any particular location. Survey data usually show discontinuities, with part of these curves not present (May, 1990).

The curves of Figure 2-1 illustrate several significant points. First, a zero-flow rate occurs under two different conditions. One is when there are no pedestrians on the facility - density is zero, and flow rate is zero. Speed is theoretical for this condition and would be selected by the first pedestrian (presumably at a high value). This speed is represented by S_f in the graphs. The second is when density becomes so high that all pedestrians must stop - the speed is zero, and the flow rate is zero, because there is no movement and pedestrians cannot pass a point on the roadway. The density at which all movement stops is called jam density, denoted by D_j in the diagrams. Between these two extreme points, the dynamics of traffic flow produce a maximizing effect.

As flow increases from zero, density also increases, since more pedestrians are on the roadway. When this happens, speed declines because of the interaction of pedestrians. This decline is negligible at low and medium densities and flow rates. As density increases, these generalized curves suggest that speed decreases significantly before capacity is achieved. Capacity is reached when the product of density and speed results in the maximum flow rate. This condition is shown as optimum speed S_o (often called critical speed), optimum density D_o (sometimes referred to as critical density), and maximum flow v_m (May, 1990).

The slope of any ray line drawn from the origin of the speed-flow curve to any point on the curve represents density, based on Equation 2-5. Similarly, a ray line in the flow density graph represents speed. As examples, Figure 2-1 shows the average free-flow speed and speed at capacity, as well as optimum and jam densities. The three diagrams are redundant, since if any one relationship is known, the other two are uniquely defined. The speed-density function is used mostly for theoretical work; the other two are used in this study to define LOS. As shown in Figure 2-1, any flow rate other than capacity can occur under two different conditions, one with a high speed and low density and the other with high density and low speed. The high-density, low-speed side of the curves represents oversaturated flow. Sudden changes can occur in the state of pedestrian traffic (i.e., in speed, density, and flow rate). LOS A through E are defined on the low-density, high-speed side of the curves, with the maximum-flow boundary of LOS E placed at capacity; by contrast, LOS F, which describes oversaturated and queue discharge traffic, is represented by the high-density, low-speed part of the functions (May, 1990).

2.6.3 Pedestrian Flow Characteristics

The qualitative measures of pedestrian flow are similar to those used for vehicular flow, such as the freedom to choose desired speeds and to bypass others. Other measures related specifically to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, to manoeuvre generally without conflicts and changes in walking speed, and the delay experienced by pedestrians at signalized and un-signalized intersections. Additional environmental factors that contribute to the walking experience and therefore to perceived level of service are the comfort, convenience, safety, security and economy of the walkway system.

Comfort factors include weather protection, climate control, arcades, transit shelters, and other pedestrian amenities. Convenience factors include walking distances, pathway directness, grades, sidewalk ramps, directional signing, directory maps, and other features making pedestrian travel easy and uncomplicated. As pointed out in Chapter one, safety is provided by the separation of pedestrians from vehicular traffic on the same horizontal plane, with malls and other vehicle-free areas and vertically above and below with overpasses and underpasses. Traffic control devices can provide time separation between pedestrian and vehicular traffic. Security features include lighting, open lines of sight and the degree and type of street activity (HCM, 2010).

2.6.4 Pedestrian Space Requirements

Pedestrian facility designers use body depth and shoulder breadth for minimum space standards, at least implicitly. A simplified body ellipse of 0.5m by 0.6m, with a total area of $0.27m^2$, is used as the basic space for a single pedestrian, as shown in Figure 2-2 below. This represents the practical minimum for standing pedestrians. In evaluating a pedestrian facility, an area of $0.74m^2$ is used as the buffer zone for each pedestrian. (HCM, 2010). A walking pedestrian requires a certain amount of forward space which is a critical dimension, since it determines the speed of the trip and the number of pedestrians able to pass a point in a given time period. The forward space in Figure 2-3 is categorized into a pacing zone and a sensory zone (Fruin J., 1987).

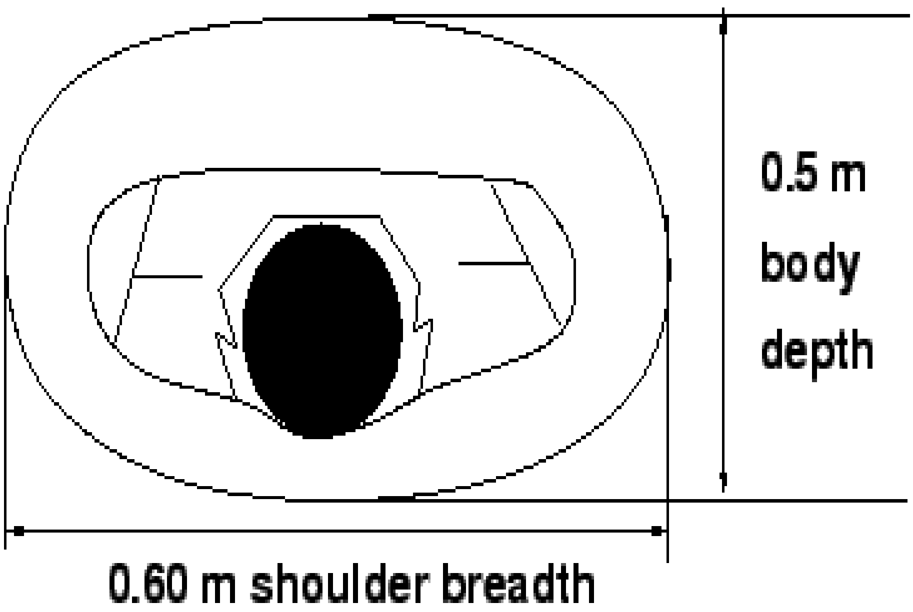


Figure 2–2: Pedestrian Body Ellipse.

Source: Fruin J., 1987

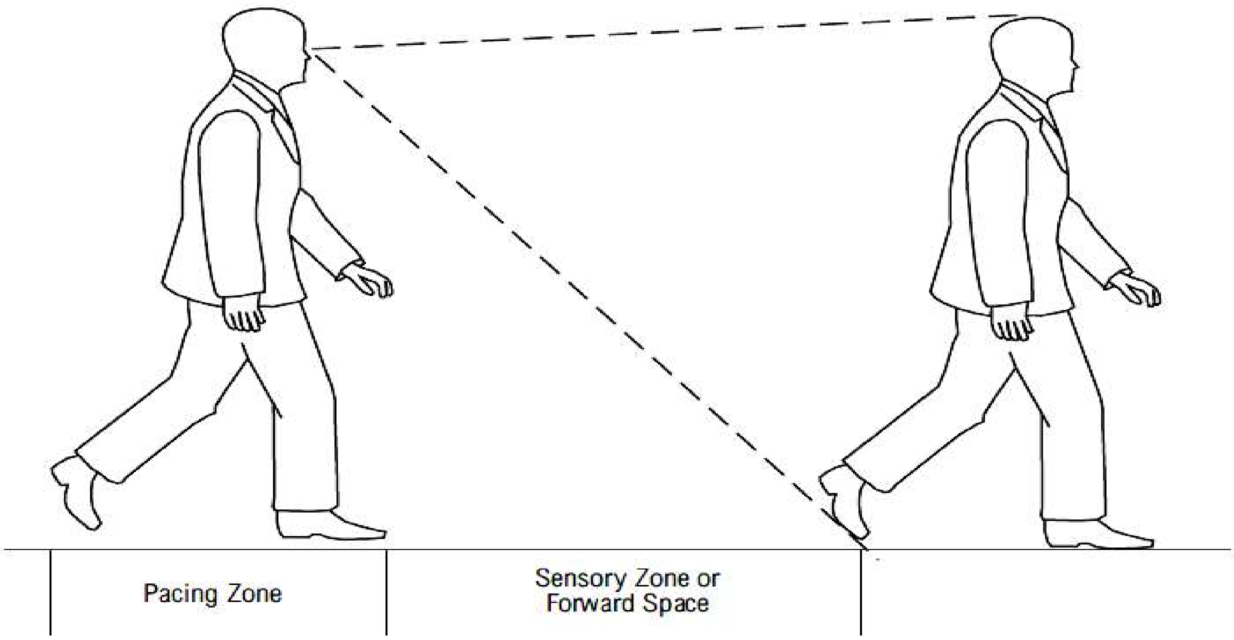


Figure 2–3: Pedestrian Space Requirements.

Source: Fruin J., 1987

2.6.5 Pedestrian Walking Speed

Pedestrian walking speed is highly dependent on the characteristics of the walking population. The proportion of elderly pedestrians (65 years old or more) and children in the population, as well as trip purpose, affect walking speed. In a national study conducted by Fitzpatrick, K. et al in 2006 on improving pedestrian safety at un-signalized crossings, the average walking speed of younger pedestrians aged 13-60 crossing streets was found to be significantly different from that of older pedestrians 1.44m/s versus 1.30m/s. For flow analysis, a default free-flow speed (that is, an average pedestrian's speed on an otherwise empty sidewalk) of 1.52m/s is appropriate for sidewalks and walkways, on the basis of average walking speeds (HCM, 2010).

2.6.6 Pedestrian Start-up Time

At crosswalks located at signalized intersections, pedestrians may not step off the curb immediately when the *WALK* indication appears, in part because of perception-reaction time and in part to make sure that no vehicles have, or are about to, move into the crosswalk area. A pedestrian start-up time of 3 seconds is a reasonable midrange value to use for evaluating crosswalks at traffic signals (HCM, 2010).

2.6.7 Speed – Density Relationships

The fundamental relationship between speed, density, and volume for directional pedestrian flow on facilities with no cross-flows, where pedestrians are constrained to a fixed walkway width (because of walls or other barriers), is analogous to that for vehicular flow. As volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream (HCM, 2010).

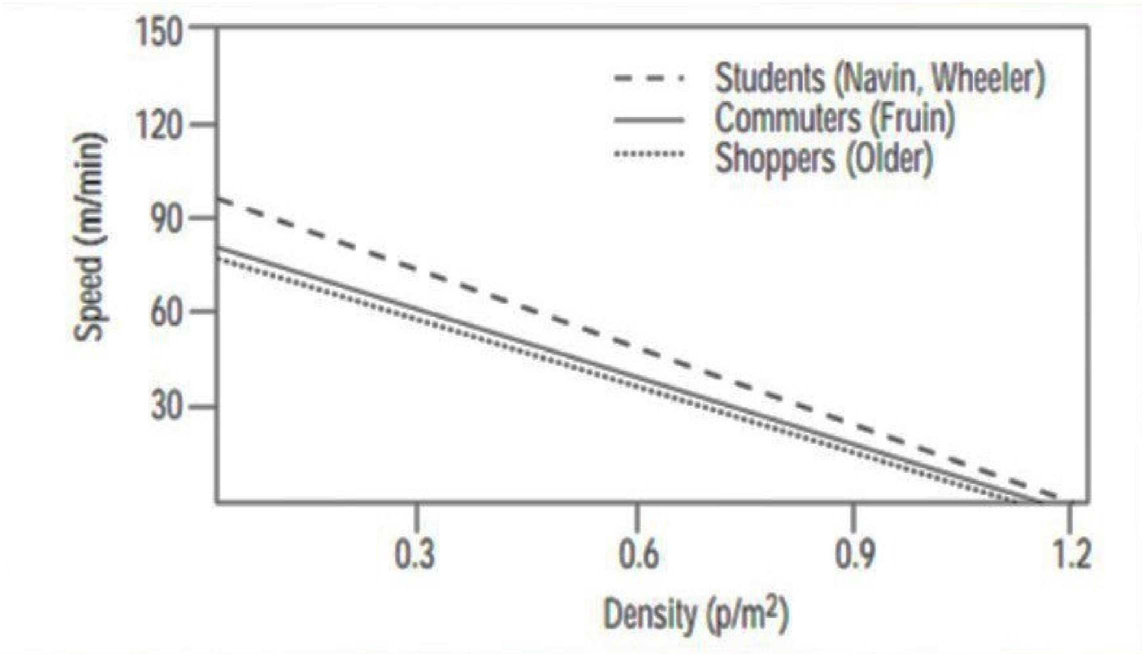


Figure 2–4: Relationship between Speed and Density for Three Pedestrian Classes.

Source: Pushkarev B., 1975

2.6.8 Flow – Density Relationship

The relationship among density, speed, and directional flow for pedestrians is similar to that for vehicular traffic streams and is expressed in the equation below (HCM, 2010):

$$V_{ped} = S_{ped} \times D_{ped}$$

Where V_{ped} *= unit flow rate (p/min/m.),*

S_{ped} *= pedestrian speed (m. /min), and*

D_{ped} *= pedestrian density (p/m²).*

The flow variable in the equation above is the unit width flow, defined earlier. An alternative, more useful, expression uses the reciprocal of density, or space:

$$V_{ped} = S_{ped} / M$$

Where M = pedestrian space (m^2/p).

2.6.9 Speed – Flow Relationships

As flow increases, speeds decline because of closer interactions among pedestrians. When a critical level of crowding occurs, movement becomes more difficult, and both flow and speed decline (Pushkarev B., 1975).

2.6.10 Speed – Space Relationships

Figure 2-5 below indicates that at an average space of less than $1.39m^2/p$, even the slowest pedestrians cannot achieve their desired walking speeds. Faster pedestrians, who walk at speeds of up to 106.7m/min, are not able to achieve that speed unless the average space is $3.72m^2/p$ or more.

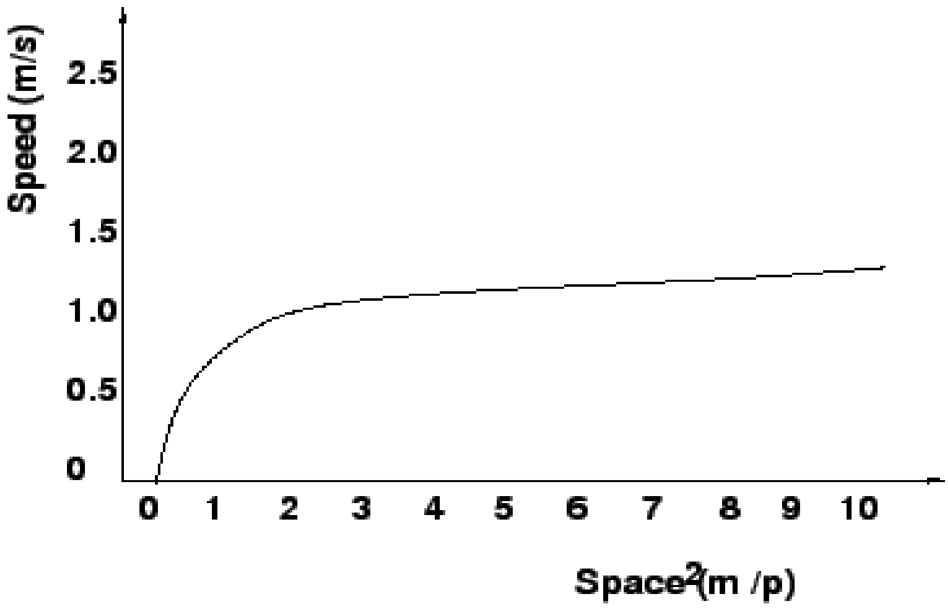


Figure 2–5: Relationships between Pedestrian Speed and Space.

Source: Pushkarev B., 1975

2.6.11 Flow on Urban Sidewalks and Walkways

Cross-flows, stationary pedestrians, and the potential for spill over outside of the walkway affect pedestrian flows on these facilities. Cross-flows of pedestrians entering or exiting adjacent businesses, getting on or off buses at bus stops, or accessing street furniture are typical on most urban pedestrian facilities. Where pedestrian volumes are high, these cross-flows will disrupt the speed-flow relationships described above, resulting in lower pedestrian speeds at equivalent flow rates. In addition to cross-flows, stationary pedestrians will be present on most urban pedestrian facilities, as pedestrians stop to talk, look in store windows, or pick up a newspaper from a vending machine. Stationary pedestrians reduce pedestrian flow by requiring pedestrians to manoeuvre around them and decreasing the available width of the walkway (HCM, 2010).

In situations where pedestrians are not physically confined within the walkway, pedestrians will often choose to walk outside of the prescribed walking area (for example, walk in the furniture zone or street) when high densities are reached. This will most often result in facilities breaking down with pedestrians spilling over into the street, before the maximum flow rate shown in Figure 2-6 is reached. Therefore, typical practice is to design pedestrian facilities for LOS C or D densities (Kittelson & Associates, 2003).

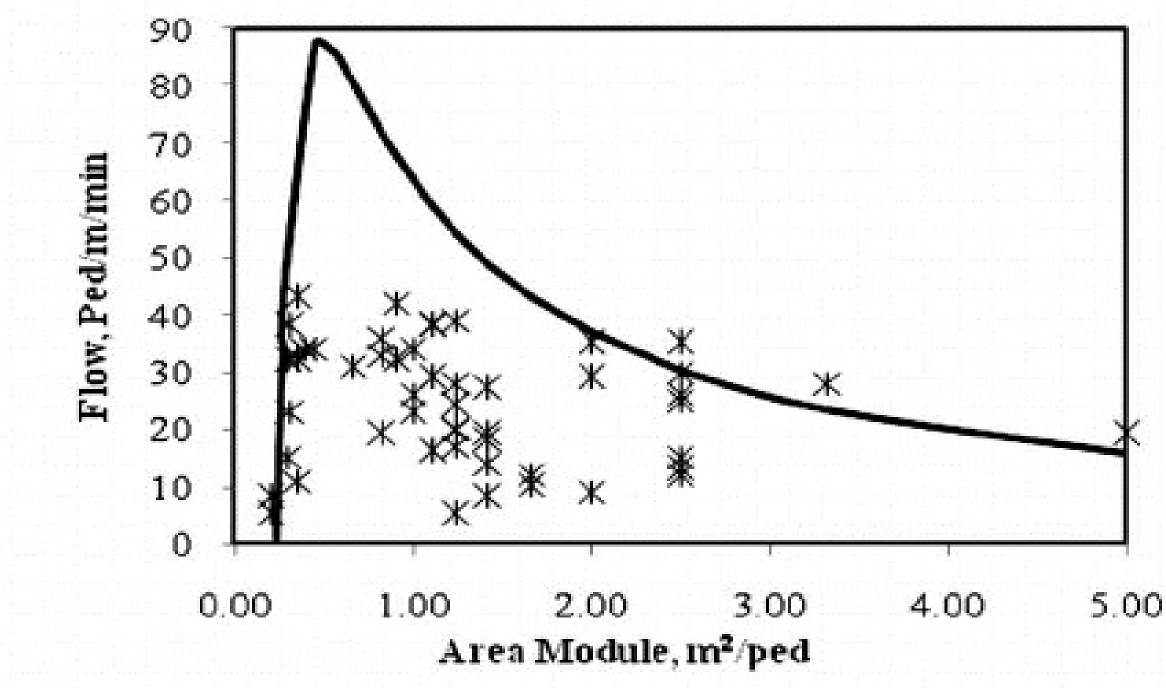


Figure 2–6: Relationships between Pedestrian Flow and Space.

Source: Pushkarev B., 1975

2.6.12 Pedestrian Type and Trip Purpose

The analysis of pedestrian flow is generally based on the mean, or average, walking speeds of groups of pedestrians. Within any group, or among groups, there can be considerable differences of inflow characteristics due to trip purpose, adjacent land use, type of group, age, mobility, cognitive ability, and other factors. Pedestrians going to and from work and using the same facilities day after day walk at higher speeds than do shoppers. Older or very young people tend to walk more slowly than do other groups. Shoppers not only tend to walk more slowly than do commuters but also can decrease the effective walkway width by stopping to window-shop and by carrying shopping bags. The analyst should adjust for pedestrian behaviour that deviates from the regular patterns represented in the basic speed, volume, and density curves (HCM, 2010).

2.6.13 Influences of Pedestrians on Each Other

According to the HCM, (2010), the ability to maintain flow in the minor direction on a sidewalk when opposed by a major pedestrian flow is difficult. For pedestrian streams of roughly equal flow in each direction, there is little reduction in the capacity of the walkway compared with one-way flow, because the directional streams tend to separate and occupy a proportional share of the walkway. However, if the directional split is 90% versus 10% and space is $0.93m^2/p$ ($10ft^2/p$), capacity reductions of about 15% have been observed. This reduction results from the minor flow using more than its proportionate share of the walkway.

Similarly, Kittelson & Associates, (2003) noted that more severe effects are seen with stairways. In contrast to their behaviour on a level surface, people tend to walk in lines or lanes in traversing stairs. A small reverse flow occupies one pedestrian lane (0.76m) of the stair's width. For a stair (1.52m) wide, a small reverse flow could consume half its capacity.

A pedestrian's ability to cross a pedestrian stream is impaired at space values less than 3.25-$3.72m^2/p$. Above that level, the probability of stopping or breaking the normal walking gait is reduced to zero. Below $1.39m^2/p$, virtually every crossing movement encounters a conflict. Similarly, the ability to pass slower pedestrians is unimpaired above $3.25m^2/p$, but it becomes progressively more difficult as space allocations drop to $1.67m^2/p$, the point at which passing becomes virtually impossible (HCM, 2010).

2.6.14 Pedestrian Facility Characteristics

Effective Walkway Width

The portion of a pedestrian facility's width that is used for pedestrian circulation is called the *effective width*. The degree to which single obstructions, such as poles, signs, and hydrants, influence pedestrian movement and reduce effective walkway width is not extensively documented. Although a single point of obstruction would not reduce the effective width of an entire walkway, it would affect its immediate vicinity (HCM, 2010).

Pedestrian Platoons

Transit facilities can create added surges in demand by releasing large groups of pedestrians in short time intervals, followed by intervals during which no flow occurs. Until they disperse, pedestrians in these types of groups move together as a platoon. Platoons can also form when passing is impeded because of insufficient space and faster pedestrians must slow down behind slower-moving ones (HCM, 2010).

2.6.15 Pedestrian Capacity on Circulation Facilities

Pedestrian capacity on facilities designed for pedestrian circulation is typically expressed in terms of *space* (square meter per pedestrian) or unit flow (pedestrians per minute per meter of walkway width). Capacity occurs when the maximum flow rate is achieved. Typical values for pedestrian circulation facilities are as follows (HCM, 2010):

- Walkways with random flow, 23 p/min/0.3m;
- Walkways with platoon flow (average over 5 min), 18 p/min/0.3m;
- Cross-flow areas, 23 p/min/0.3m (sum of both flows); and
- Stairways (up direction), 15 p/min/0.3m.

Pedestrian circulation facilities are typically not designed for capacity but rather for a less congested condition that achieves lower pedestrian throughput but that provides pedestrians with greater opportunity to travel at their desired speed with minimal conflicts with other pedestrians. Moreover, studies have shown that pedestrian facilities often break down before maximum flow rates are achieved, as a result of pedestrian spill over outside of the walkway into the furniture zone or roadway (HCM, 2010)

2.6.16 Pedestrian Level of Service

The Highway Capacity Manual, 2010 defines the Level of service (LOS) as a qualitative measure used to relate the quality of traffic service by categorizing traffic flow and assigning quality levels of traffic based on performance measure like speed and density. For pedestrian platoon flows, the Highway Capacity Manual, 2010 recommends space, flow rate and speed as presented below. These LOS criteria are based on average flow and do not consider platoon flow.

Table 2–3: Average Flow LOS Criteria for Walkways and Sidewalks

LOS	Space (m^2/ped.)	Flow Rate (ped/min/m)	Speed (m/s)	Volume (v)/Capacity (c) ratio
A	$\geq$6.0	$\leq$7	$\geq$1.32	<0.21
B	3.7-6.0	7-23	1.27-1.32	0.21-0.31
C	2.2-3.7	23-33	1.21-1.27	0.31-0.44
D	1.4-2.2	33-50	1.14-1.21	0.44-0.65
E	0.6-1.4	50-81	0.76-1.14	0.65-1.00
F	$\leq$0.6	variable	$\leq$0.76	variable

Source: HCM, 2010

Pedestrian Level of Service for Queuing Facilities

Pedestrian capacity on facilities designed for pedestrian queuing is expressed in terms of space (square meter per pedestrian). In a queuing area, the pedestrian stands temporarily while waiting to be served. In dense, standing crowds, there is little room to move, but limited circulation is possible as the average space per pedestrian increases. Queuing at or near capacity 0.19-0.28m^2/p typically occurs only in the most crowded elevators or transit vehicles. Queuing on sidewalks, waiting to cross at street corners, is more typically in the 0.28-0.56m^2/p range, which is still crowded but provides some internal manoeuvrability (HCM, 2010).

LOS A

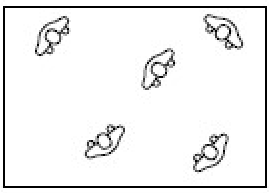


Figure 2–7: PLOS A for queuing facilities

Source: Fruin J., 1987

Average Pedestrian Space > 1.2m^2/ped. Standing and free circulation through the queuing area is possible without disturbing others within the queue. This is as shown in figure 2-7.

LOS B

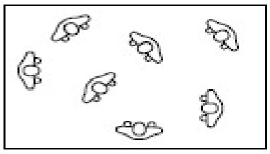


Figure 2–8: PLOS B for queuing facilities

Source: Fruin J., 1987

Average Pedestrian Space 0.9-1.2 m^2/ped. Standing and partially restricted circulation to avoid disturbing others in the queue is possible. This is as shown in figure 2-8.

LOS C

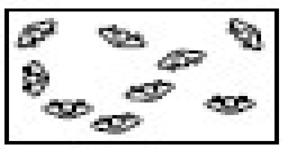


Figure 2–9: PLOS C for queuing facilities

Source: Fruin J., 1987

Average Pedestrian Space 0.6-0.9 m^2/ped. Standing and restricted circulation through the queuing area by disturbing others in the queue is possible; this density is within the range of personal comfort. This is as shown in figure 2-9.

LOS D

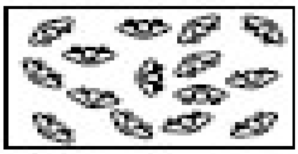


Figure 2–10: PLOS D for queuing facilities

Source: Fruin J., 1987

Average Pedestrian Space 0.3-0.6 m^2/ped. Standing without touching is possible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is uncomfortable. This is as shown in figure 2-10.

LOS E

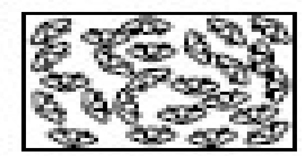


Figure 2–11: PLOS E for queuing facilities

Source: Fruin J., 1987

Average Pedestrian Space 0.2-0.3 m^2/ped. Standing in physical contact with others is unavoidable; circulation in the queue is not possible; queuing can only be sustained for a short period without serious discomfort. This is as shown in figure 2-11.

LOS F

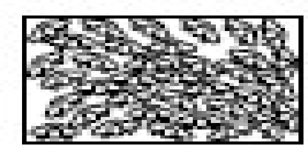


Figure 2–12: PLOS F for queuing facilities

Source: Fruin J., 1987

Average Pedestrian Space ≤ 0.2 m^2/ped. Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely uncomfortable; no movement is possible in the queue; there is potential for panic in large crowds at this density. This is as shown in figure 2-12.

Pedestrian Level of Service for Platoons

Short-term fluctuations are present in most unregulated pedestrian traffic flows because of the random arrivals of pedestrians. On sidewalks, these random fluctuations are exaggerated by the interruption of flow and queue formation caused by traffic signals. Transit facilities can create added surges in demand by releasing large groups of pedestrians in short time intervals, followed by intervals during which no flow occurs. Until they disperse, pedestrians in these types of groups move together as a platoon. Platoons also can form if passing is impeded because of insufficient space, and faster pedestrians must slow down behind slow walkers. The LOS criteria for platoon flow is as shown in the table 2-3:

Table 2–4: Platoon Adjusted LOS Criteria for Walkways and Sidewalks

LOS	Space (m^2/ped.)	Flow Rate (ped/min/m)
A	$\geq$49.23	$\leq$1.16
B	8.36-49.23	1.67-10
C	3.72-8.36	10-20
D	2.14-3.72	20-36
E	1.02-2.14	36-60
F	$\leq$1.02	>60

Source: HCM, 2010

To calculate the pedestrian flow rate, the following formula is generally used (HCM, 2010);

$V_p = V_{15} / (15 \times W_E)$, where

V_{15} = 15-minute peak flow rate (pedestrians/15-minutes),

V_p = flow (pedestrians/minute/metre),

W_E = effective walkway width (metre)

Photographic studies show that pedestrian movement on sidewalks is affected by other pedestrians, even when space is more than 3.7m^2/p. At 5.6m^2/p, pedestrians have been observed walking in a checkerboard pattern, rather than directly behind or alongside each other. These same observations suggest that up to 9.3m^2/p are necessary before completely free movement occurs without conflicts, and that at 12m^2/p, individual pedestrians are no longer influenced by others (Hall, 1966). Bunching or platooning does not completely disappear until space is about 46m^2/p or higher. Graphic illustrations and descriptions of walkway Levels of Service (LOS) are shown in the illustrations below.

LOS A

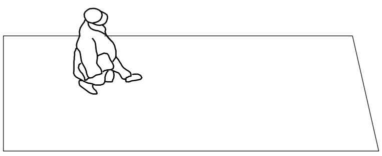


Figure 2–13: PLOS A for platoons

Source: Fruin J., 1987

Pedestrian Space > 5.6m^2/ped., Flow Rate ≤ 16ped/min/m. At a walkway PLOS A, pedestrians move in desired paths without altering their movements in response to other pedestrians.

Walking speeds are freely selected, and conflicts between pedestrians are unlikely. This is as shown in figure 2-13.

LOS B

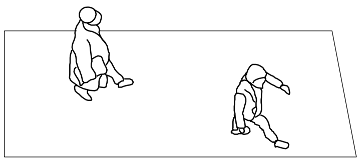


Figure 2–14: PLOS B for platoons

Source: Fruin J., 1987

Pedestrian Space > 3.7-5.6m^2/ped., Flow Rate > 16-23ped/min/m. At PLOS B, there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians, and to avoid crossing conflicts. At this level, pedestrians begin to be aware of other pedestrians, and to respond to their presence when selecting a walking path. This is as shown in figure 2-14.

LOS C

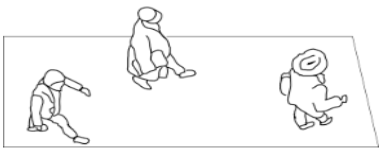


Figure 2–15: PLOS C for platoons

Source: Fruin J., 1987

Pedestrian Space > 2.2-3.7 m^2/ped., Flow Rate > 23-33ped/min/m At PLOS C, space is sufficient for normal walking speeds, and for bypassing other pedestrians in primarily unidirectional streams. Reverse-direction or crossing movements can cause minor conflicts, and speeds and flow rate are somewhat lower. This is as shown in figure 2-15.

LOS D

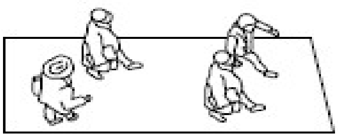


Figure 2–16: PLOS D for platoons

Source: Fruin J., 1987

Pedestrian Space > 1.4-2.2 m^2/ped., Flow Rate > 33-49ped/min/m. At PLOS D, freedom to select individual walking speed and to bypass other pedestrians is restricted. Crossing or reverse flow movements face a high probability of conflict, requiring frequent changes in speed and position. The LOS provides reasonably fluid flow, but friction and interaction between pedestrians is likely. This is as shown in figure 2-16.

LOS E

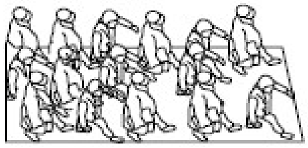


Figure 2–17: PLOS E for platoons

Source: Fruin J., 1987

Pedestrian Space > 0.75-1.4 m^2/ped., Flow Rate > 49-75ped/min/m. At PLOS E, virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range, forward movement is possible only by shuffling. Space is not sufficient for passing slower pedestrians. Cross or reverse flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with stoppages and interruptions to flow. This is as shown in figure 2-17.

LOS F

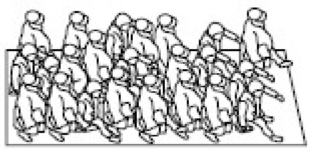


Figure 2–18: PLOS F for platoons

Source: Fruin J., 1987

Pedestrian Space ≤ 0.75 m^2/ped., Flow Rate varies p/min/m. At PLOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent, unavoidable contact with other pedestrians. Cross and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams. This is as shown in table 2-4.

Table 2–5: Service volume for a pedestrian sidewalk assuming 1.5m effective width

LOS	15-min Pedestrian Volume
A	375
B	525
C	750
D	1125
E	1725

Source: HCM, 2010

2.6.17 Pedestrian Rest Areas and Intermodal Facilities

Figure 2-19 shows a designated pedestrian rest area on the frontage zone which is adjacent to the property lines. Pedestrians can easily access these rest areas through designated routes thereby preventing conflict with those who are resting. A street furniture section is included to assist in chanelling pedestrian traffic and prevent pedestrians crossing at undesignated locations. Pedestrians tend not to enter frontage zones as they may contain retaining walls, fences, pedestrians emerging from buildings, ‘window shoppers’ or overhanging vegetation. A quick look at the study area informs us that the pedestrians within this area are unique as they utilise the frontage area to the maximum (Manual on Design of Pedestrian Network, 2009).

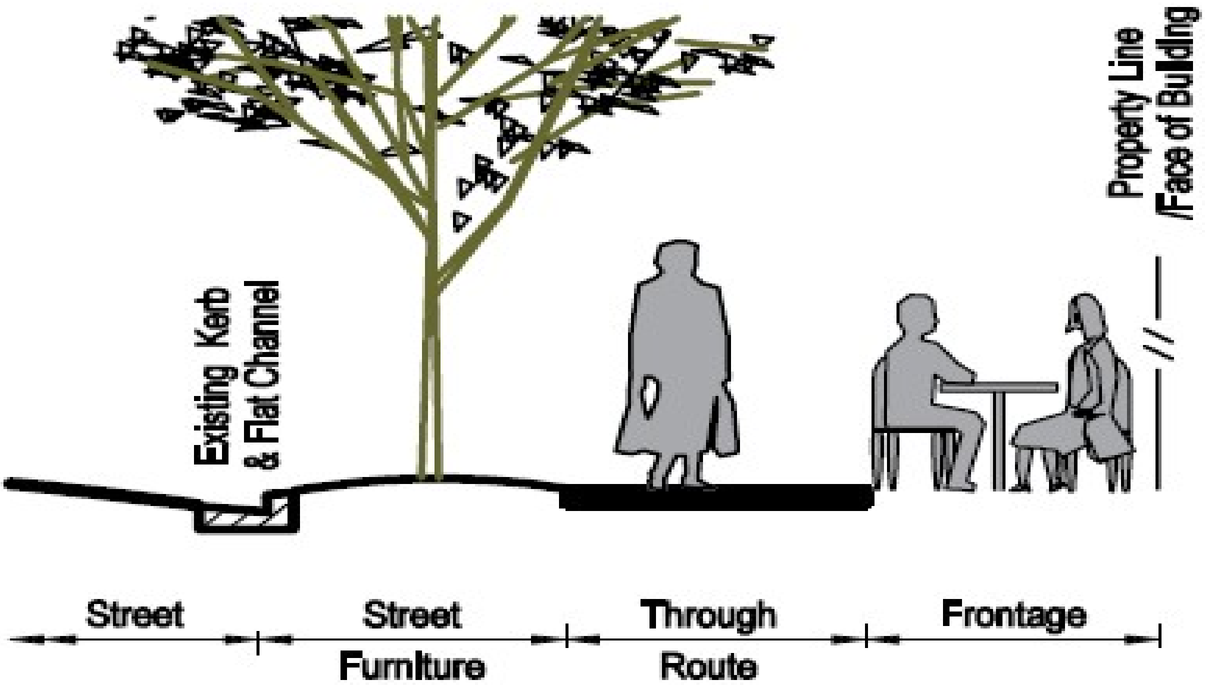


Figure 2–19: Footpath Zones.

Source: Manual on Design of Pedestrian Network, 2009

Figure 2-20 shows an example of the design recommended for passing place for wheel chairs. These passing places should be provided where the through route width is constrained to less than 1.5 metres wide, but only where it is not possible to widen the footpath over a longer distance, and never as a low-cost alternative to a full-width footpath. The advantages of passing places are; two wheelchairs can pass each other and walking pedestrians can pass stationary pedestrians, such as those waiting to use a crossing or waiting for public transport (Manual on Design of Pedestrian Network, 2009).

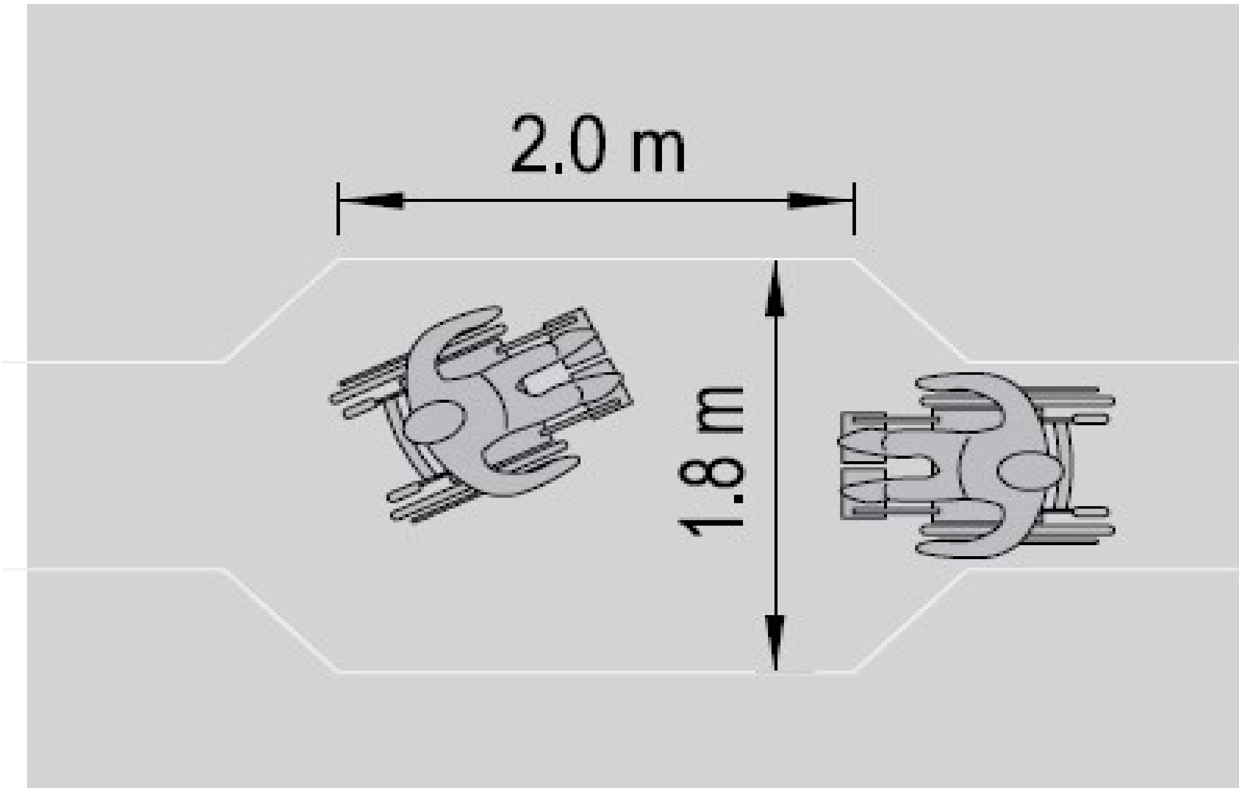


Figure 2–20: Passing Places for Wheel Chairs.

Source: Manual on Design of Pedestrian Network, 2009

Pedestrian walkways should be designed with ramps if the mean gradient is greater than five percent. Where the mean gradient exceeds three percent, walkways should be provided with rest areas as illustrated in Figure 2-21 and Figure 2-22 (Manual on Design of Pedestrian Network, 2009).

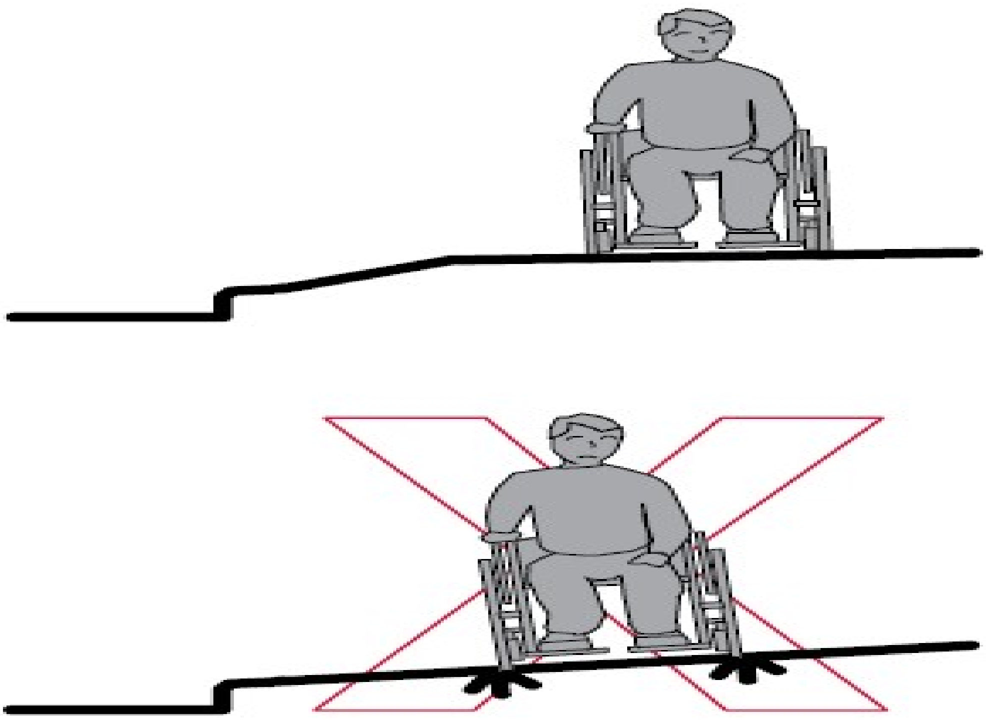


Figure 2–21: Correct and incorrect provision of cross fall.

Source: Manual on Design of Pedestrian Network, 2009

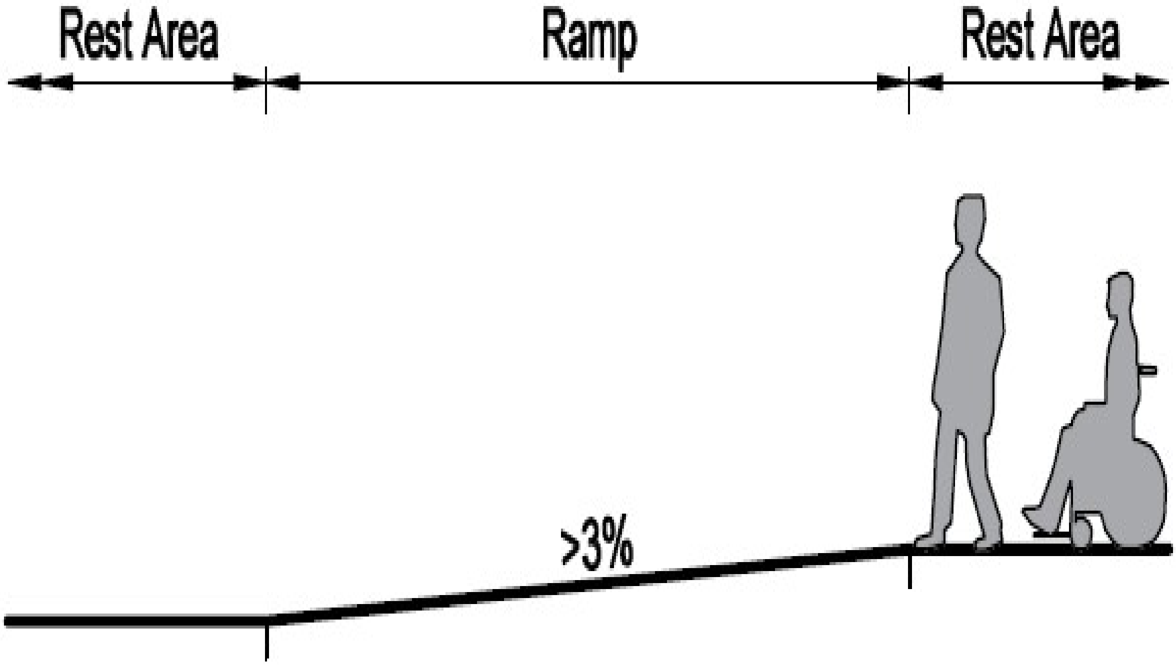


Figure 2–22: Rest Areas in Ramps

Source: Manual on Design of Pedestrian Network, 2009

Within the study area, intermodal facilities utilized by pedestrians are bus bays. These allow pedestrians to change mode from motorized transport to non-motorized transport. However, in several instances, passengers alight and board at non-designated areas. Segregation of motorized and non-motorized facilities, enforcement and proper signage would therefore assist in avoiding conflicts. When designing shared-use paths for both unsegregated and non-segregated paths, particular care needs to be taken as follows (Manual on Design of Pedestrian Network, 2009):

i. Where cyclists join the shared route to ensure they can do so safely and without conflict with pedestrians;

ii. Where the shared route ends, to ensure that cyclists do not continue to use a route intended for pedestrians only;

iii. Where one shared use route crosses another pedestrian, cyclist or shared-use route;

iv. To ensure adequate forward visibility for cyclists, who are generally moving more quickly than pedestrians;

v. To provide adequate signing to indicate the presence of pedestrians and cyclists.

In both cases it is important to:

i. Leave a lateral clearance distance of one metre on both sides of the path to allow for recovery by cyclists after a loss of control or swerving;

ii. Maintain an overhead clearance of 2.4 m over the path and the lateral clearance distance;

iii. Ideally, keep a 1.5 m separation between the path and any adjacent roadway;

iv. Ensure the gradient and cross fall comply with the most stringent best practice for pedestrians and cyclists.

Segregated paths require pedestrians and cyclists to use separate areas of the path, delineated by contrasting surfaces or markings. To ensure the vision impaired do not stray into cyclists' paths, the pedestrian and cyclist areas should be separated by a raised mountable kerb, a white thermoplastic line, a median strip of a different surface, at least one metre wide or a landscape barrier raising the pedestrian area by at least 75 mm. (Manual on Design of Pedestrian Network, 2009)

CHAPTER THREE: RESEARCH METHODOLOGY

This chapter provides the research methodology of the study, including the description of the pedestrian survey (data collection), existing documentation, interviews, field observations and photo survey, as well as the specific field research methods employed as discussed further below. The primary objective of the data collection is to facilitate the design of pedestrian walkways, with specific reference to Kenyan urban roads using the data analyzed in this study.

3.1 RESEARCH METHOD AND DESK REVIEW

In order to satisfy the objectives of the thesis, a quantitative research was carried out, with the purpose of identifying the boundary of the study area, pedestrian walkway, curb, shoulders, median, obstructions and all other pedestrian facilities. The use of surveys helped in observing pedestrian flow patterns, employing traffic volume and pedestrian volume counts, and constructing statistical models in an attempt to explain observations along the pilot urban roads.

Prior to commencing fieldwork, the author reviewed relevant literature from published works, Internet sources, to include Kenya's regulatory and institutional systems, as well as pedestrian planning design manuals and guidelines. The review of local secondary data was necessary to avoid duplication of work. With a few exceptions, the study revealed the paucity of pedestrian planning design manuals and guidelines available in Kenya, as they were mostly outdated or at the draft stage.

3.2 SITE RECONNAISSANCE

A reconnaissance site visit was conducted to familiarize with the existing conditions along the study area. The reconnaissance contributed largely to the formulation of the problem statement, which is based on the existing condition with regard to safe pedestrian movement along the study corridor.

3.3 DATA REQUIRED FOR THE STUDY

Based on the objectives of the study, the following outline presented detailed individual tasks and assignments, which would enable the effective answering of the research questions.

i. In order to measure the pedestrian flow, manual counts were carried out on the basis of pedestrians per hour.

ii. The pedestrian walking speed was determined by using a stop clock to record the speed of a given pedestrian over a predefined distance. Several pedestrians of different ages and sex were sampled and their speed recorded in order to come up with an average speed at a given time over a given distance.

iii. To determine the density, the number of people on a given footway or along the road was measured by using the moving observer method per given length. Hand tallies were used to collect the data over a predefined length by adding up those whom we met or passed and deducted those who overtook us while we counted within the predefined length. The observer was considered as a vehicle and his/her speed determined. Using the fundamental equation of traffic flow (Chapter 2, equation 2-5), which gives the flow as the product of density and space mean speed, with any two parameters known, the third can be computed. Moving observer method of traffic stream measurement was used to provide simultaneous measurement of traffic stream variables.

iv. Measuring the pedestrian space was done by establishing the number of pedestrians occupying a defined area, at every instant. A video camera was used to record the pedestrian movement across a demarcated stretch on the sidewalk. The area required or occupied by one pedestrian was determined by extracting the number of pedestrian in the area during peak and off-peak periods.

v. Origin Destination survey/walking characteristics/travel demand were done through roadside oral interviews.

vi. Delays/Queuing/Waiting time were recorded at crossing points along the urban roads by use of hand tallies at intervals, and for a given period of time. This helped to determine the time wasted by pedestrians waiting to cross the road.

vii. The pedestrian walkway width characteristics were obtained by measuring the total length of the walkway, which was compared with the total length of the walkway occupied by stalls and/or hawkers.

viii. The pedestrian walking characteristics included: pedestrians going to school; those with disabilities; pedestrians going to work; pedestrians alighting from other modes of transport, and hawkers within the study area.

In order to determine pedestrian characteristics, the study enumerators considered one pedestrian at a time and recorded their details and characteristics at various said locations, some of which include:

i. Gender
ii. Age
iii. Disability
iv. Assisting/assisted/non-assisted
v. Carrying luggage or without luggage
vi. Time in and out of defined stretch

These factors were used in determining the walking speeds of various pedestrian categories based on the investigated attributes. The locations of these studies were along sidewalks, at queuing points and points of actual crossing.

3.4 DATA COLLECTION PROCEDURE

3.4.1 Type, Duration of Study and Pedestrian Count Locations

The following data was collected:

i. Pedestrian flow counts for 7 days.

ii. Pedestrian speed by age group such as school children, adults, male and female adults with load, load size and configuration, the old. This was carried out for 7 days.

iii. Queuing study (delay study) were carried out for 3 days

iv. Walking duration for 3 days

v. Travel demand for 3 days

vi. Origin destination (O-D) survey including timing by male/female adults and school children for 3 days.

vii. Interviews were conducted with stakeholders such as KeNHA and KURA

viii. Pedestrian body ellipse measurement, which included measurement of depth (breadth) and width during the passenger O-D. (The ellipse included luggage carried on either or both of the hands or on top of the head)

ix. Road inventory and walkway width measurements.

Pedestrian traffic counts were conducted at the 4 count locations as shown in the figure 3-1 and justified in the table 3-1. The actual counts were conducted for between 3 -7 continuous days.

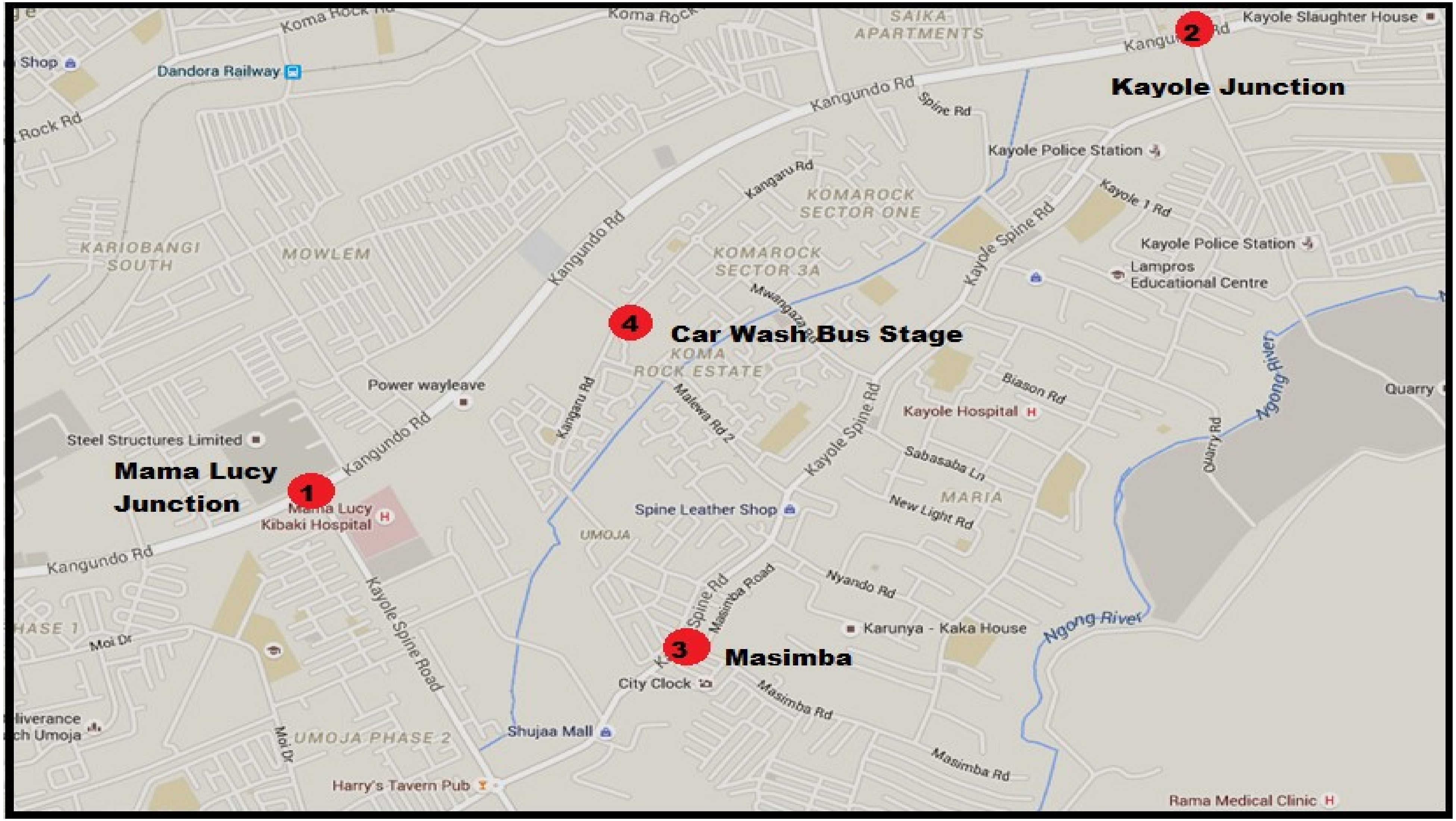


Figure 3-1: Study Points Location

Source: Google Maps, Author - November, 2015

Table 3-1: Description of Study Location Points and Types of Counts Conducted

No.	Location	Nature/ Description	Conducted Count
1	Mama Lucy Junction (Junction of *Kangundo* Road with *Kayole* Spine road at Mama Lucy hospital)	The Hospital	Pedestrian volume count **along** the three legs of the junction on either side of the road
		Steel Structure Limited	Pedestrian volume count **crossing** on *Kayole* Spine Rd at Mama Lucy Hospital
		Residential estates on either side	Moving observer method for density along Kayole spine road adjacent to Mama Lucy Hospital
		Matatu stage at the Junction	Crossing Duration Study on *Kayole* Spine Road adjacent to Mama Lucy Hospital
			Queuing delay/duration on Kayole Spine Road adjacent to Mama Lucy Hospital
2	Kayole Junction (Junction with *Kayole* Spine road near *Kayole* Slaughter)	Built up Residential Estates, Petrol Station Cooperative bank *Matatu* Bus Stage Roadside market	Pedestrian volume count **along** the three legs of the junction on either side of the road
			Pedestrian volume count **crossing** on *Kangundo* Road (towards *Saika*) and on *Kayole* Spine Road
			Moving observer method for density along *Kangundo* Road towards *Saika* and *Kayole* Spine Road
			Crossing Delay/Duration Study on *Kangundo* Road towards *Saika* and *Kayole* Spine Rd
			Queuing delay/duration on *Kangundo* Road towards Saika and on *Kayole* Spine Road
3	*Masimba* Junction (At *Masimba* Along *Kayole* Spine Road)	Shops and other commercial units Residential houses *Matatu* Stage	Pedestrian volume count **along** two legs on *Kayole* Spine Road on either Sides of the Road
			Pedestrian volume count **crossing** on *Kayole* Spine Road on either side of the junction
			Moving observer method for density along *Kayole* Spine Road towards Mama Lucy Hospital
			Crossing Delay/Duration Study on *Kayole* Spine Road
			Queuing delay/duration on *Kayole* Spine Road
4	Car wash stage Junction with *Malewa* Road	Residential Estates on either side Churches Commercial Units and Shops	Pedestrian volume count **along** two legs on *Kangaru* Road on either Sides of the Road
			Pedestrian volume count **crossing** on *Kangaru* Road on either side of the Junction
			Moving observer method for density along *Kangaru* Road
			Crossing Delay/Duration Study on *Kangaru* Road
			Queuing delay/duration on *Kangaru* Road

Source: Author, November, 2015

3.4.2 Materials

The traffic counters were provided with traffic counting equipment, data sheet(s) and written instructions prior to the count. These included clipboards, reflector jackets, umbrellas, chairs, study count forms, pens, torches, hand tallies, measuring tapes, video and still photo cameras.

3.4.3 Staff

The staff involved in carrying out surveys included enumerators, interviewers, field supervisors, data entry clerks and the study coordinator (M.Sc. Student).

3.4.4 Quality Control

The enumerators were trained before the exercise began. During counting, the field supervisors and the study coordinator would conduct a random review to ensure that the enumerators were on-duty and were tabulating information correctly.

3.4.5 Work Programme

The following work plan was deemed appropriate to ensure the work was completed as required.

Table 3–2: implemented Work Programme

Date	Activity	Site No.
Saturday 03/10/2015	Site visit and orientation, preparation of materials	All Locations
Sunday 04/10/2015	Recruitment and training of enumerators/ interviewers	All Locations
	Distribution of materials for the commencement of the study	All Locations
Monday 05/10/2015	Study began at all the locations simultaneously	All Locations
	Pedestrian Interviews were conducted	All Locations
	Delay, crossing and queuing study were conducted	All Locations
Tuesday 06/10/2015	Counts continued in the 7-day count locations	All Locations
Wednesday 07/10/2015	Counts continued in the 7-day count locations	All Locations
	Pedestrian Interviews were conducted	All Locations
	Delay, crossing and queuing studies were conducted	All Locations
Thursday 08/10/2015	Counts continued in the 7-day count locations	All Locations
Friday 09/10/2015	Counts continued in the 7-day count locations	All Locations
Saturday 10/10/2015	Counts continued in the 7-day count locations	All Locations
	Pedestrian Interview were conducted	All Locations
	Delay, crossing and queuing studies were conducted	All Locations
	Road Network inventory (measurement)	Kangundo Road
Sunday 11/10/2015	Counts continue in the 7-day count locations	All Locations
	Road Network inventory (measurement)	Kangaru and Kayole Spine
Monday 12/10/2015	Data collation, collection of materials and paying enumerators was done	All Locations
15/10/2015 – 13/11/2015	Data Entry, analysis and reporting was done	Desktop

Source: Author, November, 2015

3.5 SUMMARY OF METHODOLOGY

The data collection was carried out as planned, however, some issues that were noted included (i) the school teacher strike; it was observed that most of the schools within the area are NGO sponsored, Church sponsored or privately owned and as such data collection on school/education trips would not be affected. Some of the NGO Sponsored, Church Sponsored and Private Owned Schools within the area included: *Diwopa* Catholic Primary School, New Light Junior Academy, Komarock Junior Nursery, Lakewood School, Precious Gift School and Bridge International Academy.

CHAPTER FOUR: RESEARCH FINDINGS AND ANALYSIS

This chapter presents and analyses the results of the empirical investigation concerning the walking characteristics of pedestrians, their preferences, as well as an assessment of the adequacy of pedestrian facilities along the urban roads in *Komarock*. Findings are described in the form of tables and charts, which are thereafter used to make conclusions.

4.1 PEDESTRIAN FLOW ANALYSIS

The pedestrian flow characteristics along urban roads in *Komarock* is related to the land use in the existing area, the effective width of sidewalks, the proportion of reverse direction pedestrians, non-motor vehicle flow, and so on. The change of climate, on street parking, and so forth also had certain influences. An analysis of pedestrian flow characteristics was undertaken to establish the daily flow variation at all the locations. Thereafter, a regression curve was drawn and an equation describing pedestrian flow at each location established using multiple linear regression model (see section 2.2.2). The flows were quarterly (15-minute interval) starting from 5 am to 9 pm. Consequently, each daily flow was made up of 64 measurements of 15-minute interval each (See Figure 4-1).

Though there were variations in terms of volumes of pedestrians at various locations, the general flow pattern was similar to that of motorized traffic. As such, all the locations registered flows showing characteristic two-peak periods in the morning and in the evening. This was done for both pedestrians walking along the roadside (sidewalks) and those observed to be crossing the road. Different peak volumes were obtained for crossing traffic including the traffic on the pedestrian sidewalk. The 85^{th} percentile values were selected because they represented the variables that were accommodated by majority of the large pedestrian population during the study.

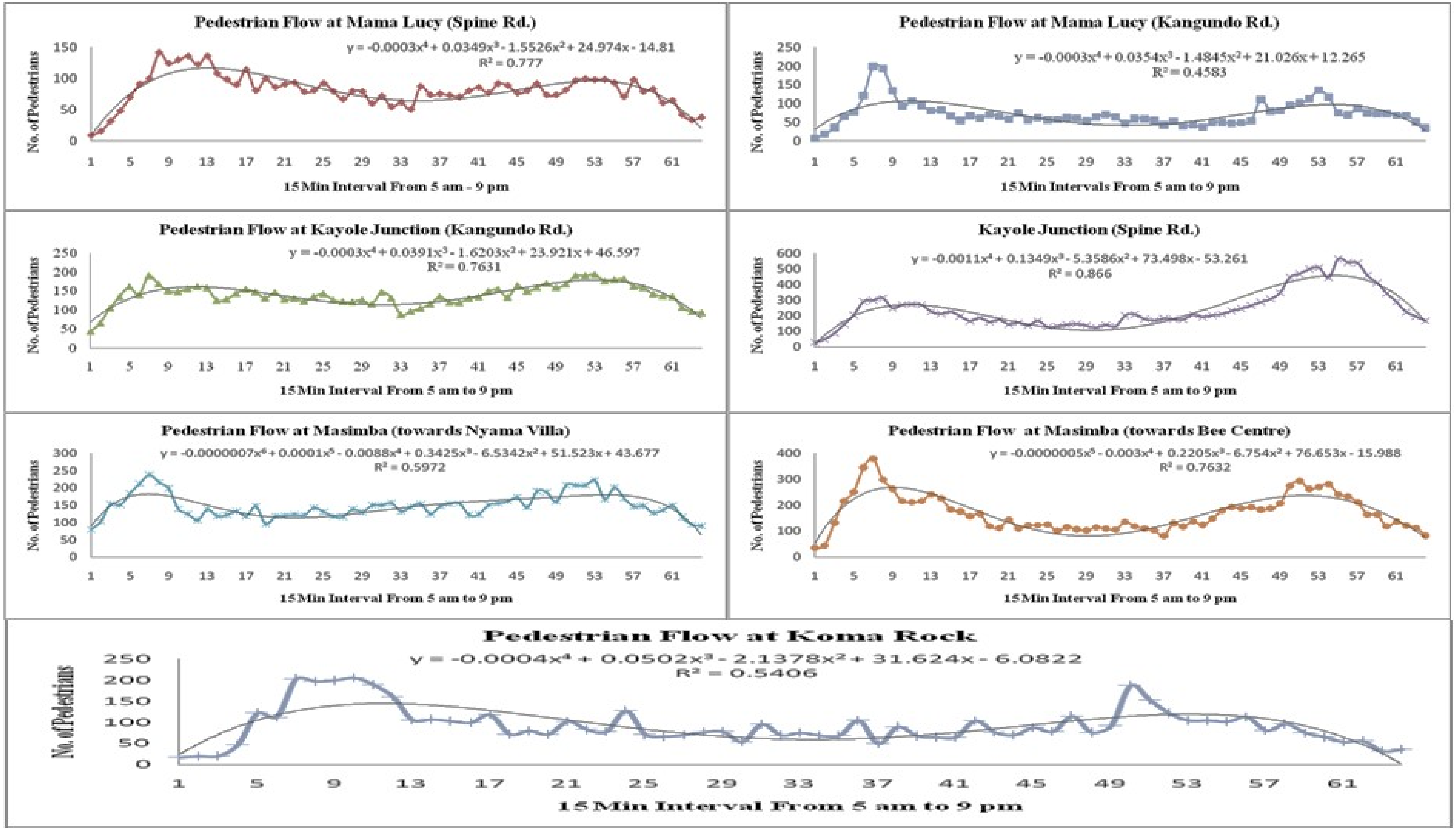


Figure 4-1: Pedestrian Quarter hourly flows at various Locations

Source: Author - November, 2015

4.1.1 The 15 Minute Pedestrian Flow along the Sidewalks (Walkways)

Mama Lucy Junction

At Mama Lucy Junction along *Kayole* Spine road, the overall pedestrian flow was low with a maximum of 142 pedestrians per 15-minute interval occurring during the morning peak. This can be attributed to low residential activity, with only the Hospital and Steel Structures Limited being the factors attracting pedestrian flow. *Figure 5.1* and the polynomial regression curve illustrate that the morning peak occurred between the 9^{th} and the 13^{th} quarter, while the evening peak occurred between the 51^{st} and the 53^{rd} quarter. However, the surveyed pedestrian volumes at Mama Lucy junction along *Kangundo* Road were slightly high, recording a maximum of 210 during the morning peak.

The pedestrian flow at Mama Lucy Junction along *Kangundo* Road was modelled using a polynomial equation of order and with an R^2 = 0.7770. This implied that the equation $y = -0.0003x^4 + 0.0349x^3 - 1.5526x^2 + 24.974x - 14.81$ was able to predict pedestrian traffic flow at Mama Lucy Hospital area along *Kayole* Spine Road up to 77.7% accuracy, where 'y' is the number of pedestrians during a 15-minute interval and 'x' is the position of the quarter during the 16-hour period. Similarly, the pedestrian flow along *Kangundo* Road is modelled by the polynomial equation $y = -0.0003x^4 + 0.0354x^3 - 1.4845x^2 + 21.026x + 12.265$ of order 4 with an R^2 value of 0.4583 implying an accuracy ability of only 45.8%.

The 85^{th} percentile flow at Mama Lucy Junction along *Kayole* Spine Road was established as 116 during weekdays, for pedestrian traffic using the sidewalk between 7.30pm and 7.45pm. During the weekends, the 85^{th} percentile flow volume recorded was 95 pedestrians between 8.00 am and 8.15 am. However, along Kangundo Road, the peak pedestrian flow volumes were 107 between 8.00 am and 8.15 am on weekdays and 84 between 6.45am and 8.30am on weekends. This is equivalent to a pedestrian flow rate of 3.6ped/min/m which is within PLOS A which requires less than 7 ped/min/m according to HCM (2010). This implies the walkway is operating within the required capacity.

Kayole Junction

At *Kayole* Junction, the sidewalk flows were measured along *Kangundo* Road and along *Kayole* Spine Road. Findings revealed that 15-minute pedestrian flows were very high along *Kayole* Spine Road with flows of up to 600, while flows along *Kangundo* Road were relatively low with maximum flow of 210 pedestrians per 15-minute interval. The equivalent pedestrian flow exhibited was 100ped/min/m, which is greater than 81ped/min/m according to HCM (2010) for PLOS F. The walkway was therefore operating beyond the required capacity.

The pedestrian flow at *Kayole* Junction along *Kangundo* Road was modelled and predicted using the polynomial equation $y = -0.0003x^4 + 0.0391x^3 - 1.6203x^2 + 23.921x + 46.597$ of order 4 with an R^2 value of 0.7631 hence an accuracy of 76.31%. Similarly, the equation for *Kayole* Spine Road, is also a polynomial of order, $y = -0.0011x^4 + 0.1349x^3 - 5.3586x^2 + 73.498x - 53.261$ and $R^2 = 0.8660$. This provides an accuracy of 86.6% in predicting the quarter hourly pedestrian flows on the sidewalks

The 85th percentile flows for *Kayole* Junction were determined during weekdays and weekends. Along *Kangundo* Road, the 85th percentile of pedestrian flow was obtained as 175 occurring between 4.30pm and 5pm; as well as between 7.15 pm and 7.30 pm during weekdays. During weekends, the 85th percentile flow along the sidewalks was 194 occurring between 5.15 pm to 5.30 pm and between 5.45 pm to 6 pm. Along *Kayole* Spine Road, the 85th Percentile pedestrian 15-minute flows was 371, occurring twice during the weekdays at 6.45 am to 7.00 am and 7.00 pm to 7.15 pm. Findings revealed that the pedestrian volumes surveyed during weekends was 361, also occurring twice between 5.15 pm to 5.45 pm. The equivalent pedestrian flow exhibited was 61ped/min/m, which is within 50-81ped/min/m according to HCM (2010) for PLOS E. This implies that the walkway was approaching its capacity limit.

Masimba Junction

The 15-minute pedestrian sidewalk flows at *Masimba* Junction were relatively high compared to those established at Mama Lucy Junction. This is because *Masimba* Junction is the main collection area for pedestrian traffic emanating from the neighbouring estates before being distributed to other roads. At this location, pedestrian flows were considered towards Bee Centre (Mama Lucy) and *Nyama* Villa (*Kayole* Junction). The surveyed pedestrian flow at *Nyama Villa* was slightly lower, with the maximum 15-minute flows recorded at approximately 250. In contrast, the section towards Bee Centre had a maximum flow of approximately 400 pedestrians per 15-minute interval. However, as with the other locations, the pedestrian flows had a characteristic two-peak period in the morning and evening.

The pedestrian volume flow towards *Nyama* Villa was modelled and predicted using the polynomial equation $y= -7(10^{-7})\ x^6+ (10^{-4})\ x^5-0.009x^4+0.343x^3-6.534x^2+51.52x+43.68$ of order 6 and $R^2 = 0.59$, hence adequately and accurately predicting the pedestrian flow as 59.72%. As for the section towards Bee Centre, the pedestrian flow was predicted using the polynomial equation $y = -5(10^{-7})\ x^5-0.003x^4+0.2205x^3-6.754x^2+76.653x-15.988$ of order 5 with $R^2 = 0.7632$ giving an accuracy of 76.3%.

The 85th percentile flow was determined as 202 pedestrians falling between 6.30 pm and 6.45 pm for the leg towards *Nyama* Villa for weekdays, and 238 pedestrians for the leg towards Bee Centre; occurring thrice at 7.15-7.30 am, 4.00-4.15 pm and 6.15-6.30 pm respectively on weekdays.

Komarock

Pedestrian flow at *Komarock* was recorded for 3 weekdays running from Monday to Wednesday for 16 hours each. The flow was similar along all sections of *Kangaru* Road due to the nature of residential estates and the population. Two peak periods were identified with values of approximately 200 pedestrians both during the morning and evening peak-hours. The pedestrian flow for *Kangaru* Road was modelled using the polynomial equation $y= -0.0004x^4+0.0502x^3-2.1378x^2+31.624x-6.0822$ of order 4 with $R^2 = 0.5406$, hence an accuracy in prediction of quarter hourly flows of 54%.

The 85th percentile flow along the sidewalks of *Kangaru* Road was found to be 128 pedestrians per 15-minute interval, occurring twice during the 16-hour count periods; between 6.15-6.30am and between 3.15-3.30 pm. Table 5.1 provides detailed findings on flow equations, R^2 values and the 85th percentile for sidewalks.

Table 4-1: Pedestrian Flow

Location	**Segment**	**85th Percentile**				**Equation**	**Order**	**R^2**
		Weekday		**Weekend**				
		Time	**Volume**	**Time**	**Volume**			
Mama Lucy (*Kangundo* Rd.)	Mama Lucy to junction	08.00-08.15	107	06.45-07.00 08.30-08.45	84	$y = -0.0003x^4 + 0.0354x^3 - 1.4845x^2 + 21.026x + 12.265$	4	0.4583
Kayole (*Kangundo* Rd.)	Junction to Mama Lucy	16.30-17.00 19.15-19.30	175	17.15-17.30 17.45-18.00	194	$y = -0.0003x^4 + 0.0391x^3 - 1.6203x^2 + 23.921x + 46.597$	4	0.7631
Kayole (Spine Rd.)	Junction to *Masimba*	06.45-07.00 19.00-19.15	371	17.15-17.30 17.30-17.45	361	$y = -0.0011x^4 + 0.1349x^3 - 5.3586x^2 + 73.498x - 53.261$	4	0.8660
Masimba (*Kayole* Spine Rd.)	*Masimba* to Nyama Villa	18.30-18.45	202			$y= -7(10^{-7})x^6+(10^{-4})x^5-0.009x^4+0.343x^3-6.534x^2 + 51.52x + 43.68$	6	0.5972
Masimba (*Kayole* Spine Rd.)	*Masimb*a to Bee Centre	07.15-07.30 16.00-16.15 18.15-18.30	238			$y = -5(10^{-7})x^5-0.003x^4+0.2205x^3-6.754x^2+76.653x-15.988$	5	0.7632
Mama Lucy (*Kayole* Spine Rd.)	Mama Lucy to Bee Centre	19.30-19.45	116	08.00-08.15	95	$y = -0.0003x^4 + 0.0349x^3 - 1.5526x^2 + 24.974x - 14.81$	4	0.7770
Komarock (*Kangaru* Rd.)	*Kangaru* Road	06.15-06.30 15.15-15.30	128			$y= -0.0004x^4+0.0502x^3-2.1378x^2+31.624x-6.0822$	4	0.5406

Source: Author, November, 2015

4.1.2 Peak Volume Flows

Pedestrian volumes were consecutively recorded during 15–minute intervals for 16 hours during the day. At the various locations, efforts were made to determine the average daily flows from where peak flows were computed. Findings revealed that the highest 15-minute flow values encountered during the 16-hour counts, which were considered to be the peak volume flows. The peak values were classified for each location for both weekend and weekday pedestrian traffic. Most of the peak flows exhibited pedestrian level of service F indicating extreme saturation of pedestrians along the walkways.

Peak Volume Flows along the Sidewalks

A summary of pedestrian volume flows along the sidewalks, during 15-minute intervals, at peak traffic for various locations are presented in Table 4-2 below:

Table 4-2: Pedestrian Peak Volume 15-minute Flows for sidewalks

Location	Sidewalk Peak 15 Minute Flows							
	Weekday				Weekend			
	Morning		Evening		Morning		Evening	
	Period	Volume	Period	Peds	Period	Peds	Period	Peds
Mama Lucy (*Kangundo* Rd.)	6.30-06.45	199	18.00-18.15	136	07.30-07.45	172	16.30-16.45	93
Kayole Junction (*Kangundo* Rd.)	06.30-06.45	191	18.00-18.15	194	08.45-09.00	175	18.30-18.45	233
Kayole Junction (Spine Rd.)	06.45-07.00	314	18.30-18.45	565	07.30-07.45	373	19.00-19.15	715
Masimba (towards *Nyama* Villa)	06.30-06.45	238	18.00-18.15	222	Weekend			
Masimba (towards Bee Centre)	06.30-06.45	378	17.30-17.45	293	Weekend			
Mama Lucy (Spine Rd.)	06.45-07.00	141	17.45-18.00	100	07.30-07.45	159	16.30-16.45	139
Komarock	07.15-07.30	205	17.15-17.30	187	Weekend			

Source: Author, November, 2015

Mama Lucy Junction

At Mama Lucy Junction along *Kangundo* Road, the peak volume flow on the sidewalk was 199 pedestrians per 15-minute interval for the morning peak (6.30-6.45 am) and 136 for the evening peak (6.00-6.15 pm) during weekdays. At the weekend, the peak volume flows were found to be 172 pedestrians for the morning peak (7.30-7.45 am) and 93 for the evening peak (4.30-4.45

pm). This implies that most pedestrians converge at Mama Lucy Junction before boarding public service vehicles to their work places.

However, for Mama Lucy junction along *Kayole* Spine road, the values were slightly lower with the morning peak-hour being 141 (6.45-7.00 am) and the evening peak-hour being 100 (5.45-6.00 pm) on weekdays. Similarly, peak 15-minute flows were recorded as 159 pedestrians for morning (7.30-7.45am) and 139 pedestrians for evening (4.30-4.45pm) at the weekend. Overall, the peak period for Mama Lucy Junction and its environs occurs between 6.30 – 7.45 am during the morning peak; and 4.30-6.15 pm during the evening peak. The peak flow of 199 pedestrians every 15 minutes was equivalent to a pedestrian flow rate 6.32ped/min/m, which is within PLOS A and requires less than 7 ped/min/m according to HCM (2010). This implies the walkway is operating within the required capacity.

Kayole Junction

The peak pedestrian volume flow along Kangundo Road was recorded at 191 pedestrians per 15-minute interval in the morning (6.30-6.45am) and 194 pedestrians in the evening (6.00-6.15pm) on weekdays. As for the weekend, the morning peak-hour was recorded at 175 pedestrians per 15-minute interval (8.45-9.00am), while the evening peak-hour was established as 233 occurring between 6.30-6.45pm. This shows a variation in peak times for weekdays and weekends with weekday peaks occurring earlier than weekend peaks.

As for sidewalk pedestrian traffic along *Kayole* Spine Road, the peak volumes were nearly double the flows along *Kangundo* Road at the same location, with 314 pedestrians for morning peak (6.45-7.00 am) and 565 for evening peak (6.30-6.45 pm) for weekday traffic. This is because *Kayole* Spine Road acts as a collector road to the adjacent neighbourhood as opposed to *Kangundo* Road, which is the main arterial road at that area. For the weekend traffic, the morning 15-minute peak was 373 pedestrians (7.30-7.45 am) and 715 pedestrians for evening peak (7.00-7.15 pm). The peak flow of 715 pedestrians every 15 minutes was equivalent to a pedestrian flow rate of 119ped/min/m hence PLOS F, as it is greater than 81ped/min/m as recommended by HCM (2010). The walkway was therefore operating beyond capacity.

Masimba Junction

At *Masimba* Junction, pedestrian volume counts were undertaken for three weekdays only. As such, the peak 15-minute sidewalk flows were computed only for weekday traffic. The peak 15-minute flows were high exceeding volume flows at *Kayole* Junction for the morning peak, but slightly lower for the evening peak. This may be due to the fact that a majority of the pedestrians leave for work at the same time. However, in the evenings, some pedestrians either go shopping, or have to pick their children from school earlier, or enjoy flexible closing times at their work places.

On Spine Road towards *Nyama* Villa, the peak 15-minute sidewalk flows was 238 pedestrians during the morning peak (6.30-6.45 am) and 222 pedestrians per 15-minute interval during the evening peak (6.00-6.15 pm). However, for the leg towards Bee Centre, the 15-minute flow volumes were significantly higher with 378 pedestrians (6.30-6.45 am) during the morning peak and 293 pedestrians (5.30-5.45 pm) during the evening peak. Generally, the morning peak-hour at *Masimba* Junction occurs between 6.30-6.45 am and 5.30 – 6.15 pm during the evening peak-hour. The peak flow of 378 pedestrians every 15 minutes was equivalent to a pedestrian flow rate of 16.8ped/min/m hence PLOS B, as it is within HCM (2010) recommended values of 7-23ped/min/m. This implies that there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians, and to avoid crossing conflicts.

Komarock

At Komarock, the pedestrian volume counts were conducted only at one location. Consequently, there was only one morning peak 15-minute interval of 205 pedestrians per 15-minutes, occurring between 7.15 – 7.30 am with the evening peak being 187 pedestrians occurring between 5.15 – 5.30 pm during weekdays. The peak flow of 205 pedestrians every 15 minutes was equivalent to a pedestrian flow rate of 9.11ped/min/m hence PLOS B, as it is within HCM (2010) recommended values of 7-23ped/min/m. This implies that there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians, and to avoid crossing conflicts.

4.2 PEDESTRIAN FLOW, SPEED AND DENSITY

In order to use traffic stream modelling, one would require data on flow, speed, and density. The fundamental equation of traffic flow gives the flow as the product of density and space mean speed, thus with two parameters known, the third can be computed. Moving car or moving observer method of traffic stream measurement has been developed to provide simultaneous measurement of traffic stream variables. It has the advantage of obtaining the complete state with just three observers, and a vehicle (in this a case, a pedestrian). The determination of any of the two parameters of the pedestrian traffic flow was used to provide the third one by the equation (Refer to Section 2.3.3, Equation 2.5):

q = u *x* k.

Where: q = flow

u = speed

k = density of pedestrian stream

Thus, moving observer method is the most commonly used method to get the relationship between the fundamental stream characteristics. This study adopted the moving observer method to determine pedestrian flow characteristics.

In this case, a pedestrian (moving observer) walked along a predefined sidewalk or road side stretch recording the start time and finish time, as this could vary over several trips. During such walking, the 'moving pedestrian' recorded the number of persons met, overtaking and overtaken by the observer (See Plates 4-1 and 4-2) Several such trips were made with traffic stream and against traffic stream throughout the day at each location, to ensure a variation in speed and density at various times of the day. Depending on what activity each pedestrian intends to carry out, he/she will either walk in a lazy or hurried manner.

Plate 4-1: Enumerator Conducting Moving Observer Survey
Source: Author, 2015

Plate 4-2: Moving Observer Survey at Mama Lucy
Source: Author, 2015

4.2.1 Effective Sidewalk Width and Area

Since the area and width of the walkways under consideration were known, determining the effective walkway width was possible after subtracting the cumulative area of obstacles. It is worth noting that the length of the various stretches along different road segments in Komarock varied due to the road features. As such, only stretches without obstacles were considered when the measurements were being undertaken. Table 4-3 provides an overview of the dimensions on the various road stretches, which were obtained using the moving observer method.

Table 4-3: Road Segments Dimensions for Moving Observer Method

Location	**Road Section**	**Sidewalk**			**Obstacles**				**Effective Area of pavement (m^2)**	**Effective width of pavement (m)**
		L (m)	**W (m)**	**Area (m^2)**	**Obstacles**	**L (m)**	**W (m)**	**Area (m^2)**		
Kayole Junction	*Kayole* Spine Road	144.20	3.40	490.30	Stalls	3.05	1.40	4.27	486.04	2.00
						1.60	1.40	2.24	483.80	2.00
						6.00	1.50	9.00	474.80	1.90
					Timber	8.40	3.80	31.92	442.88	0.00
					Parked car	4.45	1.90	8.45	434.43	1.50
					Dumped tyres	1.60	1.60	2.56	431.87	1.80
					Dumping site	4.10	3.60	14.76	**417.11**	**0.00***
	Kangundo Road	125	2.40	300	Parked trucks	4.85	1.95	9.45	290.54	0.45
						7.80	2.65	20.67	269.87	**0.00***
						4.68	1.65	7.72	262.15	0.75
						4.68	1.85	8.65	**253.49**	**0.55**
Mama Lucy	*Kayole* Spine Road	246	2.10	516.60	No Obstacles				516.60	2.10
Komarock	*Kangaru* Rd	324	1.50	486	No Obstacles				486.00	1.50

**pedestrian walkway completely occupied by obstacles*

Source: Author, November, 2015

From the Table above, the average pedestrian walkway width for Mama Lucy Junction is 2.10m, Komarock is 1.50m, Kayole Spine Road is 0.40m and Masimba is 1.50m. HCM (2010) recommends an average walkway width of 1.50m to achieve PLOS A. This is only possible on all the three sections other that Kayole Spine Road. Using the effective area, the various parameters were determined using the following equations (HCM, 2010):

i. Flow (q)

$$q = \frac{m_a + m_w}{t_a + t_w}$$

Where; q = flow in pedestrians/second

m_a = number of pedestrians met by the observer against the stream

$m_w = (m_o - m_p)$ = pedestrians overtaken – pedestrians overtaking

t_a = time against stream

t_w = time with stream

ii. Speed (u)

$$u = \frac{l}{t_w - \frac{m_w}{q}}$$

Where; q = flow in pedestrians/second

l = length of stretch

$m_w = (m_o - m_p)$ = pedestrians overtaken – pedestrians overtaking

t_w = time with stream

4.2.2 Density-Speed Relations

The fundamental relationship between speed, density, and volume for directional pedestrian flow on facilities with no cross-flows, where pedestrians are constrained to a fixed walkway width (because of walls or other barriers), is analogous to that for vehicular flow. As volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream (HCM, 2010). Figure 4-2 illustrates the flow-speed-density relationships for pedestrians in the study area.

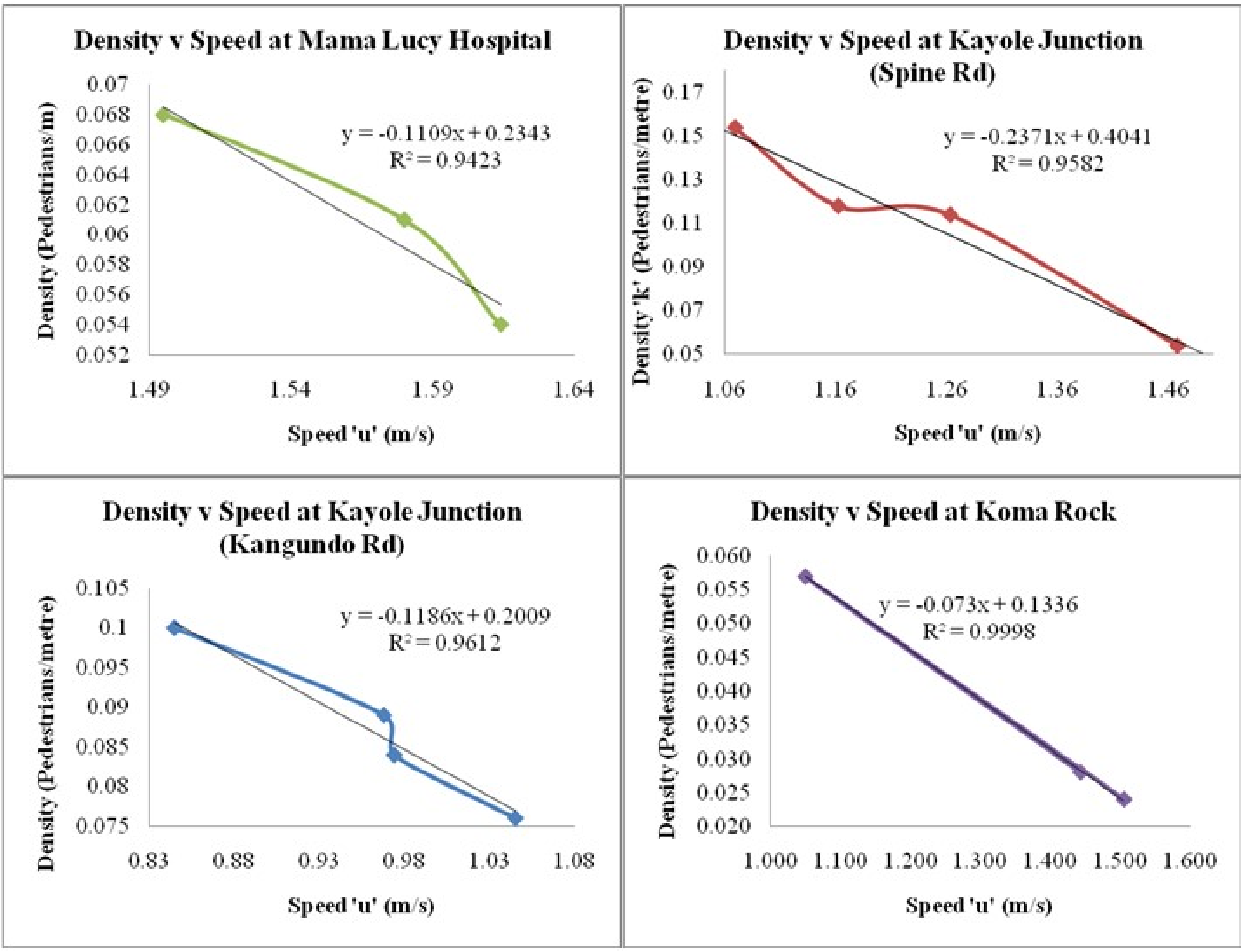


Figure 4-2: Density – Speed Relations

Source: Author, November, 2015

The density- speed graphs are negative straight lines implying that as speed increases the density decreases and vice versa. Further, high speeds were noted in areas with low pedestrian density and vice versa. Similarly, high pedestrian flow speeds in some areas of *Komarock,* were because of the well-constructed sidewalk with even cabro paved walking surface.

From the regressed graphs, the equations for density vs. speed flows were generated as well as the R^2 factors for each location. Further, analysis of various parameters of flow, speed and density were determined. These included the minimum values of the parameters, the mean values, the 85^{th} percentiles, the maximum as well as their statistical significance and standard deviation (See Table 4-4).

Table 4-4: Flow, Speed and Density Parameters

Location	Density (k) v Speed (u) Equation	R^2	N	85th Percentile/Max/Min/Average				Correlations*			
					Flow (q) (ped/sec)	Speed (u) (m/s)	Density (k) (ped/m)		Flow v Density	Flow v Speed	Density v Speed
Mama Lucy Hospital	k = -0.1109u + 0.2343	0.9423	66	85^{th}	0.125	1.928	0.078				
				Max	0.159	3.094	0.115	s	0.789	0.0297	0.803
				Min	0.017	0.869	0.010	r	0.229	0.767	-0.400
				Average	0.089	1.571	0.059	p	0.006	0.0002	0.006
Kayole Junction (*Kangundo* Rd)	k = -0.1186u + 0.2009	0.9612	128	85^{th}	0.129	1.346	0.122				
				Max	0.229	3.282	0.197	s	0.542	0.0449	0.540
				Min	0.015	0.238	0.013	r	0.437	0.812	-0.037
				Average	0.083	0.943	0.085	p	0.003	0.0002	0.003
Kayole Junction (Spine Road)	k = -0.2371u + 0.4041	0.9582	171	85^{th}	0.235	1.516	0.179				
				Max	0.495	2.039	0.343	s	0.564	0.0641	0.576
				Min	0.031	0.196	0.048	r	0.516	0.830	-0.008
				Average	0.164	1.204	0.137	p	0.003	0.0003	0.003
Komarock	k = -0.073u + 0.1336	0.9998	27	85^{th}	0.071	1.599	0.049				
				Max	0.156	2.417	0.136	s	0.720	0.0349	0.726
				Min	0.004	0.146	0.012	r	0.272	0.949	-0.025
				Average	0.050	1.350	0.038	p	0.009	0.0004	0.009

**Where s = standard deviation, r= correlation factor, p= significance at 95% confidence level*

Source: Author, November, 2015

The pedestrian speeds were highest at Mama Lucy Junction with 1.57m/s, followed by *Komarock* with 1.35m/s, *Kayole* Junction along *Kayole* Spine Road with 1.20m/s and *Kayole* Junction along *Kangundo* Road with 0.94m/s respectively. As the pedestrian density increased, speed reduced due to reduction in space for pedestrian movement. High pedestrian speeds along Mama Lucy Junction were occasioned by sufficient walkway width of averagely 2.10m, allowing more space for pedestrian movement, while the low speeds along *Kayole* Junction were occasioned by the narrow walkway width of averagely 0.40m with several obstructions which interfered with pedestrian movement. Similarly, high pedestrian speeds were realized in the morning due to the general nature of pedestrians to rush to get to work or school in good time.

4.2.3 Daily Variations in Flow Parameters

An assessment of the daily variations in pedestrian flow parameters such as flow, speed and density was undertaken at the pilot study locations. Data was collected between 5 am and 8.30 am (morning); 8.30 am and 11.30am (mid-morning); 11.30 am and 3.30pm (mid-day); and between 3.30pm to 9 pm (evening) respectively (See Table 4-5).

Table 4-5: Daily (hourly) variation in Flow Parameters

Period	**Average *flow in ped/sec***				**Average *speed in m/s***				**Average *Density in Ped/m***			
	Komarock	**Mama Lucy**	***Kayole* Spine Rd**	***Kayole Kangundo* Rd**	***Komarock***	**Mama Lucy**	***Kayole* Spine Rd**	***Kayole Kangundo* Rd**	***Komarock***	**Mama Lucy**	***Kayole* Spine Rd**	***Kayole Kangundo* Rd**
Early Morning	0.078	0.090	0.224	0.070	1.505	1.580	1.468	0.968	0.057	0.062	0.154	0.076
Mid-Morning	0.026	0.092	0.141	0.098	1.050	1.601	1.263	0.974	0.024	0.061	0.116	0.100
Mid-day	0.041	0.090	0.126	0.073	1.443	1.495	1.069	0.845	0.028	0.061	0.116	0.084
Evening	-	0.086	0.183	0.095	-	1.614	1.162	1.045	-	0.054	0.054	0.094
Average	0.048	0.090	0.169	0.084	1.333	1.573	1.241	0.958	0.036	0.060	0.110	0.089

Source: Author, November, 2015

Findings reveal that pedestrian speeds are high in the early morning, mid-day and during mid-day and mid-morning hours, with Mama Lucy recording average speeds of 1.60m/s and 1.61m/s. High speeds can be attributed to pedestrians rushing to work or school in the early mornings. Lower speeds were recorded at mid-day due to lower pedestrian densities.

4.3 PEDESTRIAN CROSSING SPEED

Pedestrian walking speed is fundamental to any roadway and traffic control design. A pedestrian crossing survey was undertaken at the pilot study locations by noting pedestrian characteristics such as gender, age category, obstruction, luggage and time. Data collection was carried out through manual time recording for pedestrians at frequent crossing locations, with the assistance of a stopwatch, capable of measuring time intervals at 1/100th of a second. Pedestrians crossing in groups (more than one pedestrian) were also noted and as such, their speed determined (See Plates 4-3 and 4-4).

Plate 4-3: Pedestrians waiting to cross the wide *Kangundo* Road

Source: Author, 2015

Plate 4-4: A Pedestrian crossing at Mama Lucy

Source: Author, 2015

It is worth noting that there are no clear or designated crossing locations on the roads in the study area such as footbridges and zebra crossings, except at Mama Lucy hospital. Findings reveal that pedestrians at the pilot study locations either crossed depending on the distance they needed to walk to desired locations, or the position of the locations with respect to adjacent land uses that generate or attract pedestrian traffic such as: shopping centres, residential areas, bus/matatu stops, hospitals and schools. Long pedestrian crossing distances increase exposure, potentially reducing pedestrian safety. They can also mean long waits for traffic during the pedestrian signal phase, with negative effects on traffic flow. Signifcant demand exists for crossing midblock because of the long distances between intersections, but drivers often fail to stop at unsignalized crosswalks. Investment in traffic signal infrastructure, including pedestrian signal lights, can help to manage flow, but such measures are expensive. Finally, overpasses and underpasses are costly and less convenient for pedestrians than surface crossings.

Pedestrian crossing speeds for various pedestrian categories, and under different circumstances were collected and analysed. These were expressed in terms of the minimum speed, mean speed, 85th percentile speed and maximum speed respectively. Further, the standard deviation and the 95% confidence intervals were also determined. Table 4-6 provides a summary of the pedestrian crossing speeds for the various pedestrian categories.

Table 4-6: Pedestrian Crossing Speed per Category

Type of Pedestrian	N	%	Crossing Speeds in Meters per Second				Standard Deviation	95% C. I*
			Minimum	Mean	85th Percentile	Maximum		
Males	464	47.6	0.407	1.447	1.983	6.133	0.881	0.006
Females	422	43.3	0.232	1.459	2.049	3.983	0.697	0.005
School Going Age	65	6.7	0.562	1.406	1.633	1.822	0.487	0.009
Middle aged adults	761	78.0	0.232	1.465	2.129	6.133	0.817	0.005
Elderly	59	6.1	0.524	1.325	1.707	3.538	0.883	0.018
Groups Population	48	4.9	0.139	1.002	1.570	2.674	0.650	0.011
Obstructed Pedestrians	172	17.6	0.139	1.064	2.009	3.187	0.813	0.009
By other Pedestrians	18	1.8	0.544	2.196	3.340	3.817	1.637	0.059
By Bicycle/Motorcycles	48	4.9	0.511	1.246	2.072	2.317	0.652	0.014
By Cars/Trucks	106	10.9	0.139	0.794	1.135	2.377	0.529	0.008
With Luggage	404	41.4	0.374	1.336	1.935	3.983	0.724	0.006
Back Pack	190	19.5	0.374	1.518	2.280	3.983	0.930	0.010
Luggage on Head	71	7.3	0.753	1.105	1.283	1.646	0.235	0.004
Shoulder luggage	119	12.2	0.572	1.185	1.551	2.317	0.451	0.006
Heavy Back luggage	24	2.5	0.685	1.333	1.984	2.120	0.745	0.023
Overall Population	975	100	0.139	1.411	1.960	6.133	0.793	0.004

*Researcher's Analysis (N= 975); *CI – Confidence Interval*

Source: Author, November, 2015

From the average pedestrian speeds calculated, middle aged adults are the fastest group among age group category (1.46m/s) followed by school going children (1.40m/s) then finally elderly (1.32m/s). Typically elderly pedestrians, with age greater than 55 years old, are likely to walk slower. This explains why in some contexts pedestrian accidents mainly involve elderly pedestrians. Insufficient time to cross safely may lead to road accident involving elderly pedestrian and the roadway design should consider this. Males and females have similar crossing speeds (1.44m/s vs 1.45m/s). Due to obstructions along the roadway, the average pedestrian crossing speed was recorded at 1.06m/s. Similarly, pedestrians with luggage crossed at an average speed of 1.34m/s, with an exception of those carrying back packs, recording a speed of

2.28m/s, which is above the 85^{th} percentile. The slowest pedestrians are those obstructed by cars and trucks recording an average speed of 0.79m/s, as they often stop midway whilst crossing, because of unyielding motorists. Additionally, pedestrians crossing the road in groups tend to register slower speeds, recording an average speed of 1.00m/s, because of the tendency of pedestrians to wait for one another while crossing the road. HCM(2010) recomends an average pedestrian crossing speed of 1.2m/s. all pedestrian categories other than those walking in groups, those with luggage or those facing obstructions achieved this speed comfortably.

4.4 EFFECTIVE CROSSING WIDTH

When providing any pedestrian device that narrow the roadway, it is important to maintain an effective crossing width for cyclists and vehicles to pass each other. Measurements for each crossing location were taken, marking the distance from one side of the road (usually the middle of the sidewalk or shoulder) to the other. Thereafter, the pedestrian speed was calculated as a quotient of distance and time for each pedestrian. Table 4-7 below shows the carriage way width together with effective crossing distances at various pedestrian crossing locations.

Table 4-7: Effective Sidewalk Crossing Width

Location	Road Segment	Shoulder/ Sidewalk A (m)	Carriageway Width (m)	Shoulder/ Sidewalk B (m)	Effective Crossing Width (m)
Mama Lucy Hospital	*Kayole* Spine Road	1.70	6.40	1.70	8.10
Kayole Junction	*Kangundo* Road	1.60	5.80	1.60	7.40
Masimba Junction	*Masimba* Junction	2.50	5.60	2.50	8.10
Komarock	Carwash Stage	1.50	5.40	1.50	6.90

Source: Author, November, 2015

Notably, on the roadways without sidewalks, pedestrians have very little space to walk. As such, pedestrians walk on the shoulder, as close to the roadway as possible, due to a lack of proper designated sidewalks in the pilot study locations. Findings reveal that the only pedestrian sidewalks which exist are a 246m long sidewalk at Mama Lucy Hospital along *Kayole* Spine Road, including another 60m of sidewalk on one side of *Shujaa* Mall respectively. Conversely, however, whereas *Kangaru* Road has no shoulder, provisions exist for a sidewalk on either side of the carriageway. This is a characteristic of an estate road, which serves *Komarock* residential estate.

4.5 WAITING TIME AND SPACE FOR PEDESTRIANS

Waiting time was considered to be the duration a pedestrian takes waiting to cross or board a bus/matatu. This is the time noted from the instant the pedestrian arrives and waits at the roadside or terminus and also depends on the amount of vehicle and pedestrian traffic. Waiting time was also dependent on the amount of pedestrian and vehicle traffic. The results on waiting time (more queuing etc) are related to facilities made for existing pedestrian crossings in the pilot study locations, such as busbay and zebra crossing (See Plates 4-5 and 4-6). Where none was available, the pedestrians would wait by the side of the road along the shoulder.

Plate 4-5: Pedestrians Queuing to Cross at Mama Lucy
Source: Author, 2015

Plate 4-6: Pedestrian Queuing at Komarock Carwash Stage
Source: Author, 2015

The intended waiting time experienced by pedestrians at walking facilities within the study area was determined by observing one pedestrian at a time. Once one pedestrian was identified, the observer started the clock until the time the pedestrian crossed the road or boarded a vehicle. Consequently, 1,028 valid samples were collected and analysed for the intended pedestrian waiting time at the four locations, and summarised in Table 4-8 below.

Table 4-8: Pedestrian Waiting/Queuing Time

Type of Pedestrian	N	%	Waiting time in seconds (s)				Standard Deviation	95% C. I
			Minimum	Mean	85th Percentile	Maximum		
Males	499	48.5%	1.560	25.70	39.36	195.66	32.87	0.252
Females	432	42.0%	1.180	30.84	60.00	184.56	34.62	0.285
Group	97	9.4%	5.010	23.46	32.78	111.44	35.60	0.619
School going age	30	2.9%	10.02	30.07	53.02	85.820	37.19	1.166
Middle aged adults	834	81.1%	1.180	29.26	51.68	195.66	35.19	0.209
The old	82	8.0%	5.090	21.10	37.33	80.550	23.41	0.443
Mixed Age Group	82	8.0%	3.820	16.89	15.10	94.370	25.98	0.491
With Disability	22	2.1%	5.120	34.35	61.60	80.550	40.48	1.465
Without Disability	1006	97.9%	1.180	27.50	47.77	195.66	33.73	0.182

Type of Pedestrian	N	%	Waiting time in seconds (s)				Standard Deviation	95% C. I
			Minimum	Mean	85th Percentile	Maximum		
Overall Population	1028	100.0%	1.180	27.50	49.09	195.66	33.73	0.180

Researcher's Data (N= 1028)

Source: Author, November, 2015

Findings revealed different waiting times for the various group categories, which were classified according to age, gender and pedestrians with or without disabilities. The average waiting time was established as 27.50 seconds, with the 85th percentile time of 49.10 seconds. Typically, pedestrians in groups tended to be more impatient as they hurried to cross the road, and thereby experienced an average wait time of 23.50 seconds, followed by male pedestrians who recorded a waiting time of 25.70 seconds.

Further observations revealed pedestrians with disability wait/queue longer taking an average of 34.40 seconds, compared to those without disability who queued or waited for an average of 27.50 seconds. Typically, female pedestrians are very patient compared to there male counters as they can wait for an average of 30.80 seconds, outdone only by people with disability (walking). However, men also recorded the highest waiting/queueing time while women recorded the lowest time attained; 195.66 seconds and 184.56 seconds respectively.

It is worth noting that older pedestrians waited/queued for shorter durations, an average of 21.1 seconds, because they received preferences at various boarding or crossing loactions. Pedestrians expect and tolerate smaller delays at unsignalized intersections than at signalized intersections. Longer waiting times of greater than 30 seconds result in very high likelyhood of pedestrians engaging in risk taking behaviour while crossing the road, according to HCM (2010). Similarly, with delays of between 10-20 seconds, pedestrians are considered of moderate risk taking behaviour.

4.6 PEDESTRIAN COMPOSITION

Pedestrian volume counts at all the four count sites (locations) were classified according to gender and age, thus separating children pedestrians from adult pedestrians. In order to determine the pedestrian composition, the study has adopted a classification where pedestrians are categorized as adult male, adult female and children pedestrians. This was because of the difficulty in categorizing pedestrians by splinter age groups. Likewise, it was difficult to determine the pedestrian age groups from observation. However, children pedestrians were slightly easy to classify due to their general physical body size and activity (school going). The following sections present the findings for pedestrian compositions by location.

Mama Lucy Junction

The majority of pedestrians at Mama Lucy Junction along *Kangundo* Road were mainly male adult pedestrians (66%), with children pedestrian accounting for 9% of the pedestrians surveyed (See Figure 4-3). However, the proportion of male pedestrians decreases along *Kayole* Spine Road with more female pedestrians recorded at 40%; and adult male pedestrians accounting for 54% of those surveyed. The increased number of female pedestrians along *Kayole* Spine Road could be attributed to the presence of the hospital, with mothers attending various clinics.

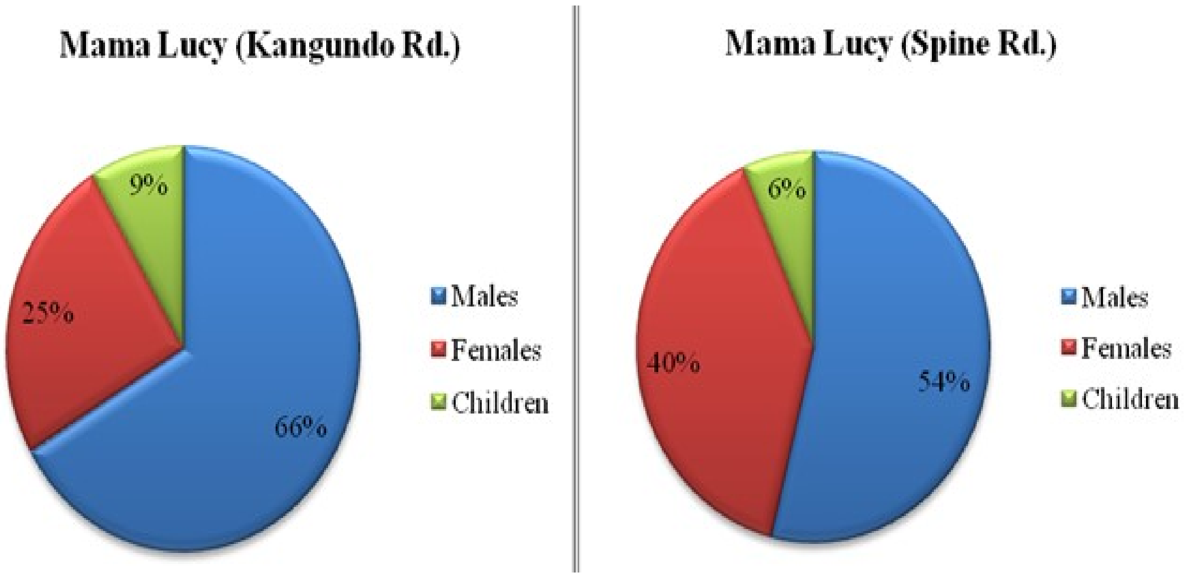


Figure 4-3: Pedestrian Composition at Mama Lucy

Source: Author, November, 2015

Kayole Junction

Pedestrian composition at *Kayole* Junction was similar to that at Mama Lucy Junction. However, there was an increased number of pedestrian children accounting for 12% and 13% of those surveyed along *Kayole* Spine Road, and Kangundo Road respectively. This was largely attributed to the many primary schools around the area, as well as the high population density. Whereas the majority of pedestrians were male in both pilot study locations, the proportion of female pedestrians was slightly higher along *Kangundo* Road, due to the market and higher number of residential buildings compared to *Kayole* Spine Road (See Figure 4-4).

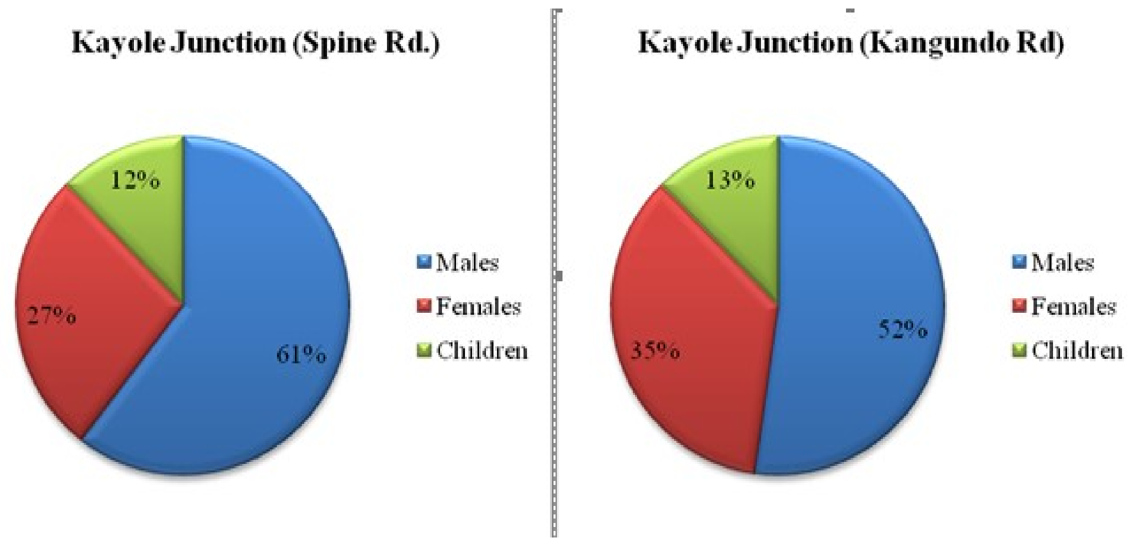


Figure 4-4: Pedestrian Composition at Kayole Junction

Source: Author, November, 2015

Masimba Junction

Observations were made for the pedestrian composition towards Bee Center and *Nyama* Villa at *Masimba* Junction. Findings revealed that the former was similar with that at *Kayole* Junction along *Kangundo* Road, due to shared settlement and population characteristics. The pedestrian composition towards Nyama Villa on the other hand, revealed a significantly higher number of children pedestrians compared to other locations, accounting for 28% of the pedestrians surveyed (See Figure 4-5). This was attributed to the number of children playing centers at *Nyama* Villa, to include several public and private primary schools in the area.

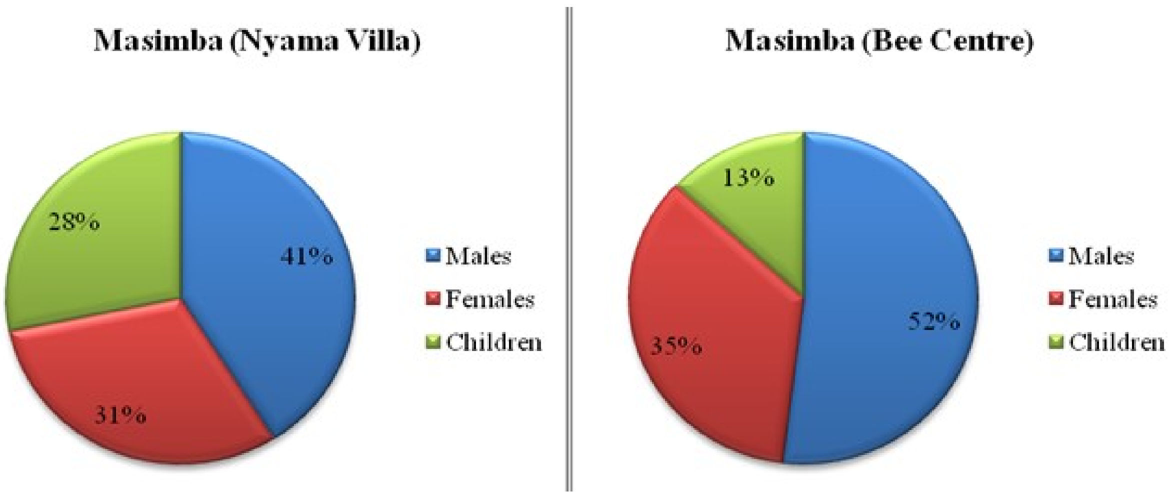


Figure 4-5: Pedestrian Composition at Masimba Junction

Source: Author, November, 2015

Komarock

Findings from *Komarock's* pedestrian composition revealed adult male pedestrians were the majority at 54%, followed by adult female pedestrians at 35% and children pedestrians at 11%. This was largely due to the population distribution, as well as the tendency male pedestrians had to engage more in outdoor activities. These findings mirror the overall aggregate pedestrian composition at the four pilot study locations illustrated in Figure 4-6.

Komarock **Overall Pedetstrian Composition**

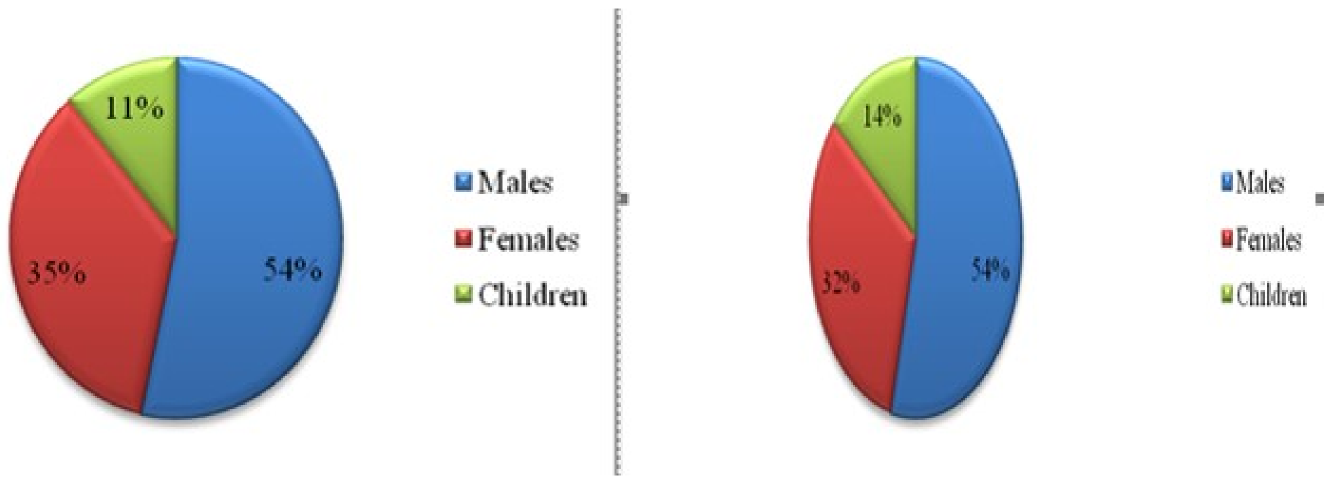


Figure 4-6: Pedestrian Composition at Komarock and the entire Study Area

Source: Author, November, 2015

4.8 PEDESTRIAN GROUP MOVEMENT

Pedestrian groups were considered as more than one pedestrian walking together at the same time and in the same direction. Generally, pedestrian group movement at *Komarock* and at Mama Lucy Junction is freely spaced, allowing for free movement along pedestrian sidewalks. Due to the higher pedestrian densities at *Masimba* and *Kayole* Junctions, however, more pedestrians were recorded per snapshot screen (See Plates 4-7 to 4-10 below).

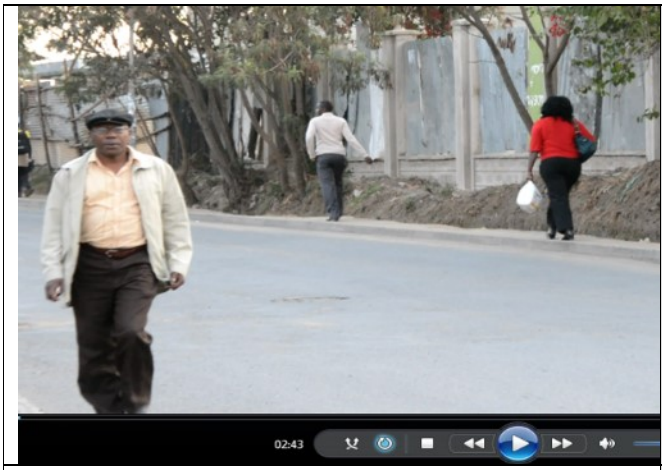


Plate 4-7: *Komarock* Video Snapshot
Source: Author, 2015

Plate 4-8: Mama Lucy Hospital Video Snapshot
Source: Author, 2015

Plate 4-9: *Masimba* Video Snapshot
Source: Author, 2015

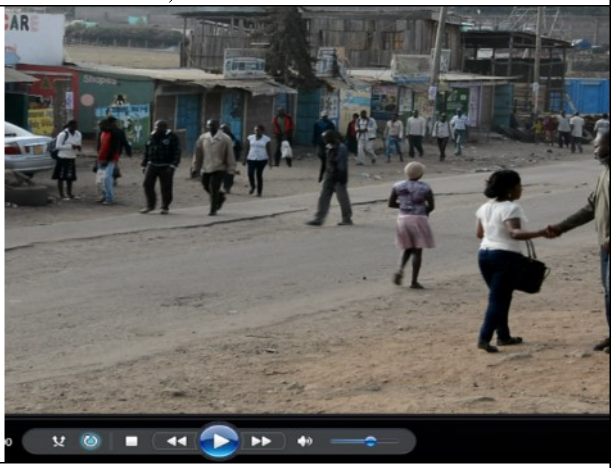


Plate 4-10*: Kayole* Junction Video Snapshot
Source: Author, 2015

On average, pedestrians walked in groups of three (3), either without any luggage or with small bags and backpacks. The videos were transcribed to extract general information such as pedestrian group size, pedestrian group composition and the pedestrian age group. In total, a sample of 203 group and single pedestrian movements were extracted, and the findings summarized in Table 4-9 below.

Table 4-9: Pedestrian Movement Characteristics (Video Analysis)

Characteristics	Frequency	%
Groups		
Single Walking	180	88.7%
As a Group	23	11.3%
Total	**203**	**100.0%**
Nature of Group		
Male Groups	14	60.9%
Female Groups	5	21.7%

Characteristics	**Frequency**	**%**
Mixed Groups	4	17.4%
Total	**23**	**100.0%**
Type of Groups		
Adults Only	13	56.5%
Children Only	6	26.1%
Adult/Children	4	17.4%
Total	**23**	**100.0%**
Luggage		
Back Pack (Bag)	37	18.2%
Box	1	0.5%
No Luggage	165	81.3%
Total	**203**	**100.0%**

Source: Author, November, 2015

4.9 Pedestrian Space and Ellipse

According to HCM, 2010, pedestrian facility designers use body depth and shoulder breadth for minimum space standards used as the basic space for a single pedestrian. A walking pedestrian requires a certain amount of forward space which is a critical dimension, since it determines the speed of the trip and the number of pedestrians that are able to pass a point in a given time period. Pedestrian space and ellipse study was carried out in order to find out whether the space allocated or occupied by the pedestrians at any given point along *Komarock* is adequate while walking, standing or carrying goods. One of the activities involved stopping pedestrians along the pilot study locations and introducing them to the study, during pedestrian interviews. The second part of activities involved taking measurements of the pedestrian's dimensions (i.e. their length and width in centimeters) using a carpenter's tape (See Plates 4-11 to 4-14 below). The length and width obtained corresponds to the x-axis and y-axis.

			
Plate 4-11: Approaching Pedestrian *Source: Author, 2015*	**Plate 4-12: Explaining Interview** *Source: Author, 2015*	**Plate 4-13: Measuring Length** *Source: Author, 2015*	**Plate 4-14: Measuring breadth** *Source: Author, 2015*

A total of 552 sets of valid measurements were obtained, with 222 conducted at *Kayole* Junction and 330 at Mama Lucy Hospital. A conventional pedestrian ellipse is as shown in the Figure 4-8 below.

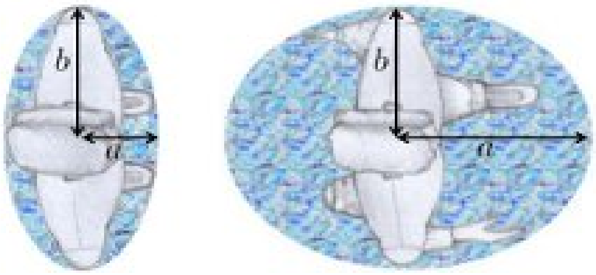


Figure 4–7: Pedestrian Ellipse Shape

Source: Chraibi et al, 2010

According to Chraibi (2010), the area of the ellipse shape of a pedestrian can be determined from the equation below (Chraibi et al, 2010);

$$A_{\text{ellipse}} = \pi ab$$

Where ‘a’ and ‘b’ are the semi-major and semi-minor axes, (½ of the ellipse's major and minor axes), respectively. In this case, ‘a’ and ‘b’ is ½ of length and width respectively. The findings are shown in the Table 4-10 below:

Table 4-10: Pedestrian Ellipse

Measurement	*Kayole* Junction			Mama Lucy Hospital			Aggregate		
	L (cm)	W (cm)	Area (m^2) (πab)	L (cm)	W (cm)	Area (m^2) (πab)	L (cm)	W (cm)	Area (m^2) (πab)
Frequency (N)	222			330			552		
Mean	59.73	40.55	0.200	58.80	37.64	0.18	59.17	38.81	0.19
85th Percentile	70	54	0.276	69	48.65	0.255	69	51	0.263
Maximum	440	100	1.694	430	79	1.757	440	100	1.757
Minimum	30	18	0.042	28	12	0.028	28	12	0.028
Standard deviation, s	29	13	0.149	30	11	0.145	30	12	0.147
Variance	825	169	0.022	914	119	0.021	877	141	0.022
95% Confidence level	0.116	0.052	0.001	0.104	0.038	0.001	0.102	0.041	0.001

Source: Author, November, 2015

From the findings, the average pedestrian ellipse measurement obtained was $0.26m^2$. This is slightly less than Fruin’s recommended value of $0.27m^2$ and $0.22m^2$ from Manjanja (2013).

4.10 ORIGIN AND DESTINATION SURVEYS

Origin – Destination Surveys are studies done to establish pedestrian travel patterns. It helps understand pedestrian route choice and also determines future pedestrian travel patterns. Interviews are normally conducted to establish pedestrian movement characteristics. (See Plates 4-15 and 4-16 below).

	
Plate 4-15: Interview at Mama Lucy Hospital *Source: Author, 2015*	**Plate 4-16: Interview at *Kayole* Junction** *Source: Author, 2015*

As such, origin destination zones by trip-end method were developed for *Kayole* Junction and Mama Lucy. Zones adjacent to the interview location were designated local zones while zones enveloping the local zones were considered external zones. Due to the realistic nature and extent of walking, the external zones were within a radius of the town area with far distances from Nairobi such as Thika, Nakuru and the rest of the country considered only up to that extent. The table below shows the Origin-Destination Zones for Mama Lucy Hospital and *Kayole* Junction.

In order to understand the origin – destination of the pedestrians in the study area, it was important to determine the establishments at their origin and destination. For the purposes of this thesis, establishment is defined by the purpose of presence, or the purpose served by the place for example, work place, residential and recreational. Table 4-11 summarizes the data collected on establishment of origin and destination at the pilot study locations.

Table 4–11: Establishment Origin-Destination

Establishment	Mama Lucy Hospital		*Kayole* Junction		Aggregate			
	Origin	Destination	Origin	Destination	Origin		Destination	
	F	F	F	F	F	%	F	%
Residential	154	176	100	89	254	48.7%	265	49.1%
Workplace	3	19	5	1	8	1.5%	20	3.7%
Factory	9	7	9	14	18	3.4%	21	3.9%
Education Institute	24	7	23	3	47	9.0%	10	1.9%
Hospital	36	33	9	19	45	8.6%	52	9.6%
Construction site	14	6	9	19	23	4.4%	25	4.6%
Shop/Market	39	22	19	21	58	11.1%	43	8.0%
Warehouse/Terminal	10	8	2	6	12	2.3%	14	2.6%
Hawking	1	1		13	1	0.2%	14	2.6%
Others	36	46	20	30	56	10.7%	76	14.1%
Total	**326**	**325**	**196**	**215**	**522**	**100.0%**	**540**	**100.0%**

N=550

Source: Author, November, 2015

From the findings, 48.7% of the trips originated at the interviewees' homes and 49.1% terminated at interviewees' homes. This implied that *Komarock* area was more of a residential neighborhood.

4.10.1 Stop over and Modal Change

When pedestrians make trips, there is a tendency to stop at certain locations before proceeding to complete their trip. Further, pedestrians might have to change mode before arriving at their destination. The study sought to establish the frequency and prevalence of stop over and mode change. The finding for the two locations as well as the aggregate statistic is shown in the Table 4-12 below.

Table 4-12: Pedestrian Stop over and Mode Change

	Stop Over				Mode Change				Aggregate			
	Mama Lucy		Kayole		Mama Lucy		Kayole		Stop Over		Mode Change	
	F	%	F	%	F	%	F	%	F	%	F	%
Yes	102	29.7%	58	24.3%	32	13.0%	46	32.2%	160	27.4%	78	20.1%
No	242	70.3%	181	75.7%	214	87.0%	97	67.8%	423	72.6%	311	79.9%
Total	**344**	**100%**	**239**	**100%**	**246**	**100%**	**143**	**100%**	**583**	**100%**	**389**	**100%**

Source: Author, November, 2015

Of the 583 valid responses on stop over, 27.4% had stop over locations with 20.1% of the 383 indicating that they would have mode change.

4.10.2 Origin and Destination Zones

In order to establish the trip matrices around the study area, the following zones were adopted (See Figure 4-8).

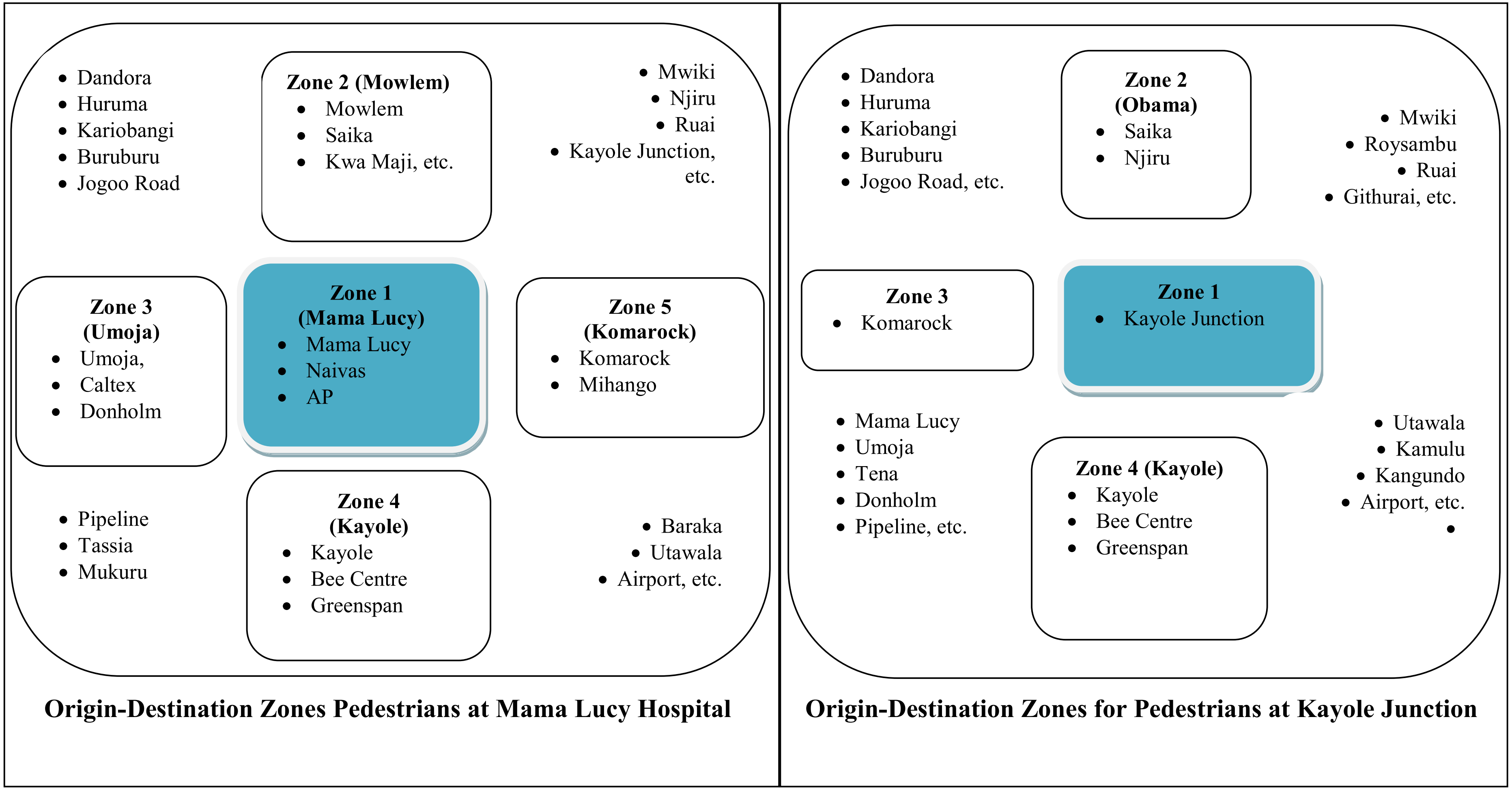


Figure 4–8: Origin-Destination Zones

Source: Author, November, 2015

4.10.3 Pedestrian Trip Matrices

From the zones, trip matrices were obtained from the data with separation to establish pedestrians who did not have a change in mode (walked for the entire trip) and those who had change in mode (used other means at some point in their trip). The trip matrices based on the zones are shown in the Table 4-13 below.

Table 4–13: Origin –Destination Pedestrian Trip Matrices

Origin zones	Kayole Junction (No Change in Mode)						Kayole Junction (With change in Mode)					
	Destination Zones					TOTAL	Destination Zones					TOTAL
	1	2	3	4	External		1	2	3	4	External	
1	10	9	3	1	2	**25**	0	1	0	1	4	**6**
2	19	0	1	2	8	**30**	2	2	0	0	5	**9**
3	8	14	11	0	13	**46**	0	1	4	0	3	**8**
4	0	1	1	0	2	**4**	0	1	1	1	2	**5**
External	7	6	10	2	9	**34**	4	4	4	0	4	**16**
TOTAL	**44**	**30**	**26**	**5**	**34**	**139**	**6**	**9**	**9**	**2**	**18**	**44**

Origin zones	Mama Lucy Hospital (No Change in Mode)							Mama Lucy Hospital (No Change in Mode)						
	Destination Zones						TOTAL	Destination Zones						TOTAL
	1	2	3	4	5	External		1	2	3	4	5	External	
1	7	8	19	0	3	13	**50**	2	3	4		1	5	**15**
2	2	2	5	2	1	11	**23**	1	2	5	1	0	6	**15**
3	11	5	13	6	0	5	**40**	5	1	3	0	0	5	**14**
4	4	7	17	2	0	21	**51**	1	5	1	3	0	3	**13**
5	2	1	0	0	0	1	**4**	0	0	0	0	0	3	**3**
External	7	3	9	6	0	21	**46**	9	7	3	3	0	14	**36**
TOTAL	**33**	**26**	**63**	**16**	**4**	**72**	**168**	**18**	**18**	**16**	**7**	**1**	**36**	**96**

Source: Author, November, 2015

From the matrix analysis, it is realized that out of the 447 pedestrians who provided information on how they intended to accomplish their trips, 307 (68.7%) would complete their trip without any change in mode meaning they will walk their entire trip. Further, for those walking their entire trip, majority of the trips were within the local zones (57.6% for *Kayole* Junction and 69.6% for Mama Lucy Hospital). This explains why they complete their trips by walking.

For pedestrians having change in mode during their trip, majority of their trips were made from local zones to external zones and from external zones to external zones traversing the interview location. For *Kayole* Junction, trips involving external zones where pedestrians used more than one mode accounted for 68.2% of the total trips while for Mama Lucy Hospital, they accounted for 60.4%.

4.10.4 Walking Distances and travel Matrices

Apart from the analysis on the matrices, the researcher also undertook to establish the average distance for each of the trips or matrix cluster. The centroid of the clustered locations for the zones was considered to be the average point of origin. As such, an estimated point of origin defining each zone was established. For example, a zone referred to as *Umoja* was located at the approximately central location of *Umoja* Estate including *Tena, Umoja* one, *Umoja* two and Inner core. The average distance for the epicenter (interview location) to local zones, external zones and the distances between local zones as well as between external zones were established. Consequently, number of pedestrians covering those distances was determined by grouping the pedestrians from the local zones and externals from the study locations. The Table 4-14 below shows the average distances covered for various travels within the study area.

Table 4–14: Average distances Covered by Travel Matrix

Movement	Mama Lucy Hospital					*Kayole* Junction					Aggregate				
	Distance (Kms)	No Change in Mode		Change in Mode		Distance (Kms)	No Change in Mode		Change in Mode		Distance (Kms)	No Change in Mode		Change in Mode	
		F	%	F	%		F	%	F	%		F	%	F	%
Centre to Centre	0	9	4.2%	0	0.0%	0	10	7.2%	0	0.0%	0	19	5.4%	0	0.0%
Centre to Local	2.58	49	22.7%	15	16.0%	2.13	40	28.8%	4	9.1%	2.36	89	25.1%	19	13.8%
Local to Local	4.07	61	28.2%	21	22.3%	2.53	30	21.6%	10	22.7%	3.30	91	25.6%	31	22.5%
Centre to External	5.67	20	9.3%	14	14.9%	5.64	9	6.5%	8	18.2%	5.66	29	8.2%	22	15.9%
Local to External	6.33	56	25.9%	30	31.9%	6.73	41	29.5%	18	40.9%	6.53	97	27.3%	48	34.8%
External-External	7.2	21	9.7%	14	14.9%	10.2	9	6.5%	4	9.1%	8.70	30	8.5%	18	13.0%
Total		**216**	**100%**	**94**	**100%**		**139**	**100%**	**44**	**100%**		**355**	**100%**	**138**	**100%**

Source: Author, November, 2015

From the table, it is noted that the majority of the respondents who walk the whole length of their trip without changing mode is between one local zone and an external zone traversing the interview location (center). This group covers on average 6.53km and account for 27.3% of the 355 pedestrians in this category. However, it is worth noting that a combined majority of 56.1% of the respondents walking the entirety of their trip cover less than 3.5km (average 3.3km) and are between the local zones and the center of interview. Further, 5.4% of the 355 pedestrians were noted to move around the interview location while going about their daily activities with their only mode of movement being walking.

Of the 138 pedestrians expected to change mode of travel, 34.8% were making trips between the local zones to the external zones thus covering, on average, 6.53km. These relatively long distances of walking could take nearly 2 hours of travel time. Significantly, a combined total of 63.7% of trips involving change in mode were made to and from the external zones. Further, there were no trips where the pedestrians changed mode within the location of study (center to center). From the analysis, 244 out of the 493 pedestrians accounting for 49.5% walk on average 5.66 km or more with on 25.8% walking less than 3 km.

4.10.5 Pedestrian Composition from Interviews

The other characteristics determined from the pedestrian interviews included pedestrian group composition, platoon sizes, luggage carrying and commodity. The surveys (interviews) were done to classify pedestrians as Adult males, Adult females and Children. Further, the number of pedestrians in the platoons was also noted. Further, it was noted whether the pedestrian was carrying any luggage, the type of luggage and the extent to which it was filled. The Table 4-15 below shows the findings at each location with summary as aggregate.

Table 4–15: Pedestrian Movement Characteristics from Interviews

Pedestrian Composition	Mama Lucy		Kayole Junction		Aggregate (Total)	
	Frequency	%	Frequency	%	Frequency	%
Adult Male	159	48.5%	135	60.8%	294	53.5%
Adult Female	143	43.6%	62	27.9%	205	37.3%
Child	26	7.9%	25	11.3%	51	9.3%
Total	**328**	**100.0%**	**222**	**100.0%**	**550**	100.0%
No. of Persons in Platoon						
1	177	56.2%	156	70.6%	333	62.1%
2	106	33.7%	45	20.4%	151	28.2%
3	25	7.9%	9	4.1%	34	6.3%
4	**4**	1.3%	**7**	3.2%	11	2.1%
>4	**3**	1.0%	**4**	1.8%	7	1.3%
Total	**315**	**100%**	**221**	**100.0%**	**536**	**100.0%**
Carrying Goods						
Yes	162	49.2%	116	55.0%	278	51.5%
No	167	50.8%	95	45.0%	262	48.5%
Total	**329**	**100%**	**211**	**100.0%**	**540**	**100.0%**
Luggage Size by Volume Filled						
¼	50	35.7%	33	32.0%	83	34.2%
½	36	25.7%	28	27.2%	64	26.3%
¾	18	12.9%	13	12.6%	31	12.8%
1.0	**36**	25.7%	**29**	28.2%	65	26.7%
Total	**140**	**100%**	**103**	**100.0%**	**243**	**100.0%**
Commodity Carried						
Food Crop	10	6.5%	4	3.3%	14	5.1%
Cash Crops	2	1.3%	0	0.0%	2	0.7%
Petroleum Products	0	0.0%	0	0.0%	0	0.0%

Pedestrian Composition	Mama Lucy		Kayole Junction		Aggregate (Total)	
	Frequency	%	Frequency	%	Frequency	%
Milk/Fish/Vegetables	3	1.9%	2	1.7%	5	1.8%
Construction Materials	6	3.9%	5	4.1%	11	4.0%
Chemical Products	4	2.6%	2	1.7%	6	2.2%
Livestock	2	1.3%	0	0.0%	2	0.7%
Metal/Machinery	2	1.3%	1	0.8%	3	1.1%
Forestry Products	4	2.6%	0	0.0%	4	1.5%
Households	19	12.3%	6	5.0%	25	9.1%
Others (Back Packs, Hand bags, etc.)	102	66.2%	101	83.5%	203	73.8%
Total	**154**	**100%**	**121**	**100%**	**275**	**100%**

Source: Author, November, 2015

Of the 328 valid responses on gender at Mama Lucy Hospital, 43.6% were adult females with 48.5% being adult males. Children accounted for 7.9% of the interviews. This near even split between adult male and female pedestrians are largely due to the fact that the location was at a health facility. Thus, a good number of women (mothers) were attending various pre-natal and post-natal clinics. *Kayole* Junction, being a mix of market, bus stage and residential area, had a high majority of respondents being men (60.8%) followed by women (27.9%) with the proportion of children being significantly high at (11.3%). On aggregate, the study interviews comprised of 53.5% men, 37.3% women and 9.3% children. This is reflective of the walking tendency attributed to the strenuous nature of walking as a mode of travel.

From the interview, efforts were made to note and record the number of persons in the platoon from which the respondent were walking. A total of 536 valid records were obtained including both Mama Lucy Hospital and *Kayole* Junction. It emerged that majority of the pedestrians walked as single units forming 56.2% of the population at Mama Lucy Hospital, 70.6% at *Kayole* Junction and 62.1% on average for both locations. Further, on average of the two locations, 28.2% of the pedestrians observed at both the two locations walk in platoons of 2 pedestrian each. Only 3.4% of the pedestrians walk in platoons of 4 pedestrians or more.

On average, 51.5% of 540 pedestrians carried luggage, which included small objects like handbags, back packs, shopping bags and carry bags. Further, from the observation, it emerged that most of the luggage (bags) were less than half full (60.5%) with 26.7% being absolutely full. In terms of commodity carried by the pedestrians, it emerged that pedestrians mainly carried varied assorted commodities collectively referred to as others (73.8%). Some of these commodities include polythene bags, envelopes, backpacks, handbags and various hawking merchandise. These various items did not fall in the broad categories defined in the interview forms, and as such were always specified by the interviewers.

Apart from the assorted commodities referred to as others, other categorized commodities also had significant prevalence as noted during the interviews. These included; household goods at 9.1%, food crops at 5.1% and construction materials (paint, nails, and tools) at 4.0%.

4.10.6 Pedestrian Trip Purpose

Each and every pedestrian on the road had a reason for making trips, which varied from location to location, and are determined by the time of the day. Males, females and children have different reasons for making their trips. During the survey, data was collected to capture the trip purpose by category of gender as well as being adult or children. The Table 4-16 below shows the findings.

Table 4-16: Pedestrian Trip Purpose

Pedestrian		Home to work	Home to school	work related	Business	Social/ Recreation	Shopping	Medical	Return to work	Tourism	Others	Total
Adult Male	Frequency	158	4	20	22	19	17	18	6	3	16	283
	(%)	55.8%	1.4%	7.1%	7.8%	6.7%	6.0%	6.4%	2.1%	1.1%	5.7%	100%
Adult Female	Frequency	36	5	14	25	29	27	49	1	1	17	204
	(%)	17.6%	2.5%	6.9%	12.3%	14.2%	13.2%	24.0%	0.5%	0.5%	8.3%	100%
Child	Frequency	0	41	0	0	1	4	2	0	0	1	49
	(%)	0.0%	83.7%	0.0%	0.0%	2.0%	8.2%	4.1%	0.0%	0.0%	2.0%	100%
Total	**Frequency**	**194**	**50**	**34**	**47**	**49**	**48**	**69**	**7**	**4**	**34**	**536**
	(%)	**36.2%**	**9.3%**	**6.3%**	**8.8%**	**9.1%**	**9.0%**	**12.9%**	**1.3%**	**0.7%**	**6.3%**	**100%**

Source: Author, November, 2015

A majority of adult male pedestrians made trips from home to work accounting for 55.8% of the total male respondents interviewed. The other trips purposes are evenly distributed for adult males with work related at 7.1% and business at 7.8%. For adult females, a majority of the trips were made for medical reasons (24.0%), followed by home to work at 17.6% and social/recreation at 14.2%. Further, there was a significant proportion of adult females going for shopping trips (13.2%) and business trips (12.3%). As for the children, their main trip purpose was home to school and back at 83.7% followed by shopping at 8.2% and medical at 4.1%.

4.11 PEDESTRIAN POPULATION PROJECTION

It is expected that as the economy improves, the pedestrian population within the study area is bound to increase. This is because the need for facilities such as housing, recreation and health among others is bound to increase. A population growth rate of approximately 2.7% per annum has been used to calculate the future pedestrian peak flows. This is as shown in Table 4-17 below;

Table 4–17: Pedestrian Population Projection

Location	Weekday					
	Time	Flow (2015)	Flow (2016)	Flow (2017)	Flow (2018)	Flow (2019)
Mama Lucy	19.30-19.45	116	119	122	126	129
Kayole Junction	19.00-19.15	371	381	391	402	413
Masimba Junction	18.15-18.30	238	244	251	258	265
Komarock	15.15-15.30	128	131	135	139	142
Max. Flow in Study Area		**371**	**381**	**391**	**402**	**413**
Mama Lucy	06.30-06.45	199	204	210	216	221
Kayole Junction	18.30-18.45	565	580	596	612	629
Masimba Junction	06.30-06.45	293	301	309	317	326
Komarock	07.15-07.30	205	211	216	222	228
Max. Flow in Study Area		**565**	**580**	**596**	**612**	**629**
Mama Lucy	08.00-08.15	95	98	100	103	106
Kayole Junction	17.30-17.45	361	371	381	391	402
Max. Flow in Study Area		**361**	**371**	**381**	**391**	**402**
Mama Lucy	07.30-07.45	172	177	181	186	191
Kayole Junction	19.00-19.15	715	734	754	774	795
Max. Flow in Study Area		**715**	**734**	**754**	**774**	**795**

Source: Author, November, 2015

The peak pedestrian population rises gradually from 371 in 2015 to 413 in 2019 in the evenings and from 565 in 2015 to 629 in 2019. In calculating the effective walkway width, W_{E}, the following formula is used (HCM, 2010):

$V_p = V_{15} / (15 \text{ x } W_E)$, where

V_{15} = 15-minute peak flow rate (pedestrians/15-minutes),

V_p = flow (pedestrians/minute/metre),

W_E = effective walkway width (metre),

The flow (V_p) to be used is such that a minimum level of service of B (16-23ped/min/m) is achieved. This is then projected for five years (2015-2019). To obtain the optimum width, the lower value of 16ped/min/m is therefore used as per table 2-3. The results obtained are summarized in Table 4-18:

Table 4–18: Projected Walkway Width after Increased Pedestrian Population

Location	Weekday															
	Time	2015			2016			2017			2018			2019		
		V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e
Mama Lucy	19.30-19.45	116	16	0.5	119	16	0.5	122	16	0.5	126	16	0.5	129	16	0.5
Kayole Junction	19.00-19.15	371	16	1.5	381	16	1.6	391	16	1.6	402	16	1.7	413	16	1.7
Masimba Junction	18.15-18.30	238	16	1.0	244	16	1.0	251	16	1.0	258	16	1.1	265	16	1.1
Komarock	15.15-15.30	128	16	0.5	131	16	0.5	135	16	0.6	139	16	0.6	142	16	0.6
Max. Flow in Study Area		**371**			**381**			**391**			**402**			**413**		
Mama Lucy	06.30-06.45	199	16	0.8	204	16	0.9	210	16	0.9	216	16	0.9	221	16	0.9
Kayole Junction	18.30-18.45	565	16	2.4	580	16	2.4	596	16	2.5	612	16	2.6	629	16	2.6
Masimba Junction	06.30-06.45	293	16	1.2	301	16	1.3	309	16	1.3	317	16	1.3	326	16	1.4
Komarock	07.15-07.30	205	16	0.9	211	16	0.9	216	16	0.9	222	16	0.9	228	16	1.0
Max. Flow in Study Area		**565**			**580**			**596**			**612**			**629**		
Location	**Weekend**															
	Time	**2015**			**2016**			**2017**			**2018**			**2019**		
		V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e
Mama Lucy	08.00-08.15	95	16	0.4	98	16	0.4	100	16	0.4	103	16	0.4	106	16	0.4
Kayole Junction	17.30-17.45	361	16	1.5	371	16	1.5	381	16	1.6	391	16	1.6	402	16	1.7
Max. Flow in Study Area		**361**			**371**			**381**			**391**			**402**		
Mama Lucy	07.30-07.45	172	16	0.7	177	16	0.7	181	16	0.8	186	16	0.8	191	16	0.8
Kayole Junction	19.00-19.15	715	16	3.0	734	16	3.1	754	16	3.1	774	16	3.2	795	16	3.3
Max. Flow in Study Area		**715**			**734**			**754**			**774**			**795**		

Source: Author, November, 2015

From the table 4-18 above, the effective walkway width in 2015 varies from 1.50m to 3.00m, 2016 varies from 1.50m to 3.10m, 2017 varies from 1.60m to 3.10m, 2018 varies from 1.60m to 3.20m and 2019 varies from 1.70m to 3.30m. This implies that as the pedestrian population increases, the space required to accommodate the pedestrians also increases in order to accommodate smooth flow.

CHAPTER FIVE: DISCUSSIONS OF RESULTS

This chapter discusses the research findings from the pedestrian capacity study carried out along the urban roads in *Komarock.* A comparison is made against the results obtained in other pedestrian flow characteristic studies, as well as the commonly used design standards when planning and designing pedestrian facilities.

5.0 PEDESTRIAN FLOW ANALYSIS

The flow analysis was determined for the pedestrian traffic walking along the sidewalks and those crossing at specific locations. The parameters of flow analysed were 85th percentile flows and peak volume flows as summarized in the Table 5-1 below.

Table 5–1: Summary of 15-minute Pedestrian Sidewalk Flow

Location	Weekday				Weekend			
	85th Percentile		Peak		85th Percentile		Peak	
	Time	Flow	Time	Flow	Time	Flow	Time	Flow
Mama Lucy Junction	19.30-19.45	116	06.30-06.45	199	08.00-08.15	95	07.30-07.45	172
Kayole Junction	19.00-19.15	371	18.30-18.45	565	17.30-17.45	361	19.00-19.15	715
Masimba Junction	18.15-18.30	238	06.30-06.45	293				
Komarock	15.15-15.30	128	07.15-07.30	205				
Max. Flow in Study Area		**371**		**565**		**361**		**715**

Source: Author, November, 2015

Similarly, the flow parameters for crossing pedestrians were also summarized taking the highest values of the 85th percentile and the peak volume flows per location (See Table 5-2).

Table 5–2: Summary of 15-Minute Pedestrian Crossing Flows

Location	Weekday				Weekend			
	85^{th} Percentile		Peak		85^{th} Percentile		Peak	
	Time	Flow	Time	Flow	Time	Flow	Time	Flow
Mama Lucy	11.15-11.30	46	06.45-07.00	135	17.00-17.15	33	06.15-06.30	64
Kayole Junction	18.45-19.00	150	19.00-19.15	185	19.00-19.15	150	19.00-19.15	228
Masimba	07.15-07.30	102	18.30-18.45	117				
Komarock	08.30-08.45	24	19.15-19.30	45				
Max. Flow in Study Area		**150**		**185**		**150**		**228**

Source: Author, November, 2015

Only Kayole Junction experienced PLOS F with a pedestrian flow rate of 94ped/min/m. This implied that walkway was therefore operating beyond capacity. Pedestrians will then look for alternative places to walk and as such cases of pedestrian-vehicle conflict will increase. Mbeche et al (2001) recorded a maximum pedestrian flow rate of 79ped/min/m within the CBD while

Fruin (1971) recorded a maximum value of 81ped/min/m. This observation on the PLOS agrees with the HCM, (2010). Further, according to HCM 2010, pedestrian facilities are not designed to provide LOS A during peak periods, but rather a lower LOS that reflects the balance between individual travellers, society desires and financial resources.

5.1 PEDESTRIAN FLOW, SPEED AND DENSITY

Volume or pedestrian traffic flow is a parameter common to both uninterrupted- and interrupted-flow facilities, but speed and density applies primarily to uninterrupted flow. The Table 5-3 below shows a summary of flow, speed and density relationships for pedestrians in the study area.

Table 5–3: Summary of Pedestrian Flow-Speed-Density Relations

Location	Flow (Pedestrians per second)				Speed (m/s)				Density (pedestrians/m^2)			
	85th Percentile	Max	Min	Aver	85th Percentile	Max	Min	Aver	85th Percentile	Max	Min	Aver
Mama Lucy	0.125	0.159	0.017	0.089	1.928	3.094	0.869	1.571	0.078	0.115	0.010	0.059
Kayole Junction	0.129	0.229	0.015	0.083	1.346	3.282	0.238	0.943	0.122	0.197	0.013	0.085
Masimba	0.235	0.495	0.031	0.164	1.516	2.039	0.196	1.204	0.179	0.343	0.048	0.137
Komarock	0.071	0.156	0.004	0.050	1.599	2.417	0.146	1.350	0.049	0.136	0.012	0.038
***Study area**	**0.187**	**0.495**	**0.004**	**0.097**	**1.780***	**3.282**	**0.146**	**1.267**	**0.153***	**0.343**	**0.010**	**0.080**

Source: Author, November, 2015   ** - Values used to plot figure 5-2*

According to the Highway Capacity Manual (2010), the recommended average pedestrian speed along a pedestrian walkway should be approximately 1.52m/s. Findings reveal, that the average speed within Komarock is 1.27m/s, implying that the capacity of the pedestrian walkway should be increased to accommodate the recommended pedestrian speed. Similarly, studies from the UK's Transport for London (TFL, 2010) recommend an average pedestrian speed of approximately 1.33m/s using Public Transport Accessibility Levels. A comparison with other studies such as Mbeche et al (2001), which established average speeds of 1.11m/s within the Nairobi CBD; and Fruin (1970), which established average speeds of 1.34m/s reveal that the average pedestrian speed in *Komarock* is low. Low pedestrian speeds in *Komarock* may be due to reduced walkway widths to accommodate pedestrians. It should also be noted that pedestrians who cross the roads tend to walk much faster to avoid oncoming traffic as observed by Mbeche et al (2001).

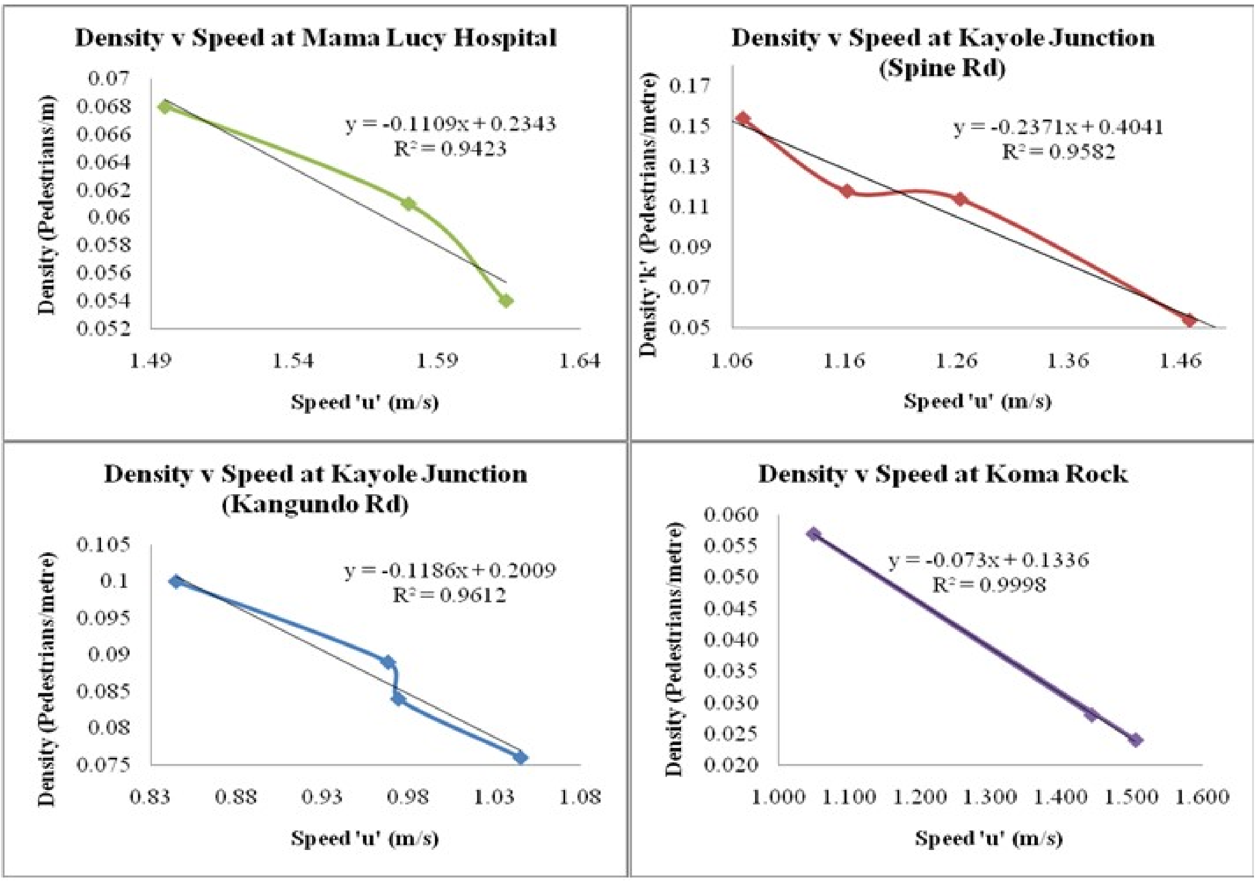
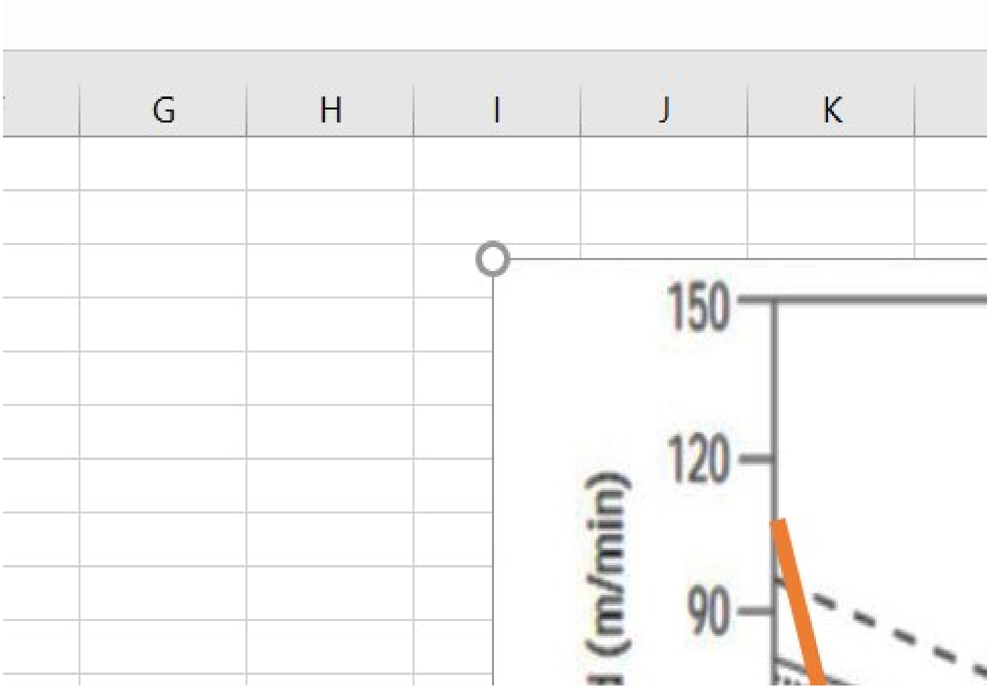


Figure 5–1: Density – Speed relations

Source: Author, November, 2015

Notably, as the pedestrian volume and density increases, the pedestrian speed will decline due to closer interactions among pedestrians, particularly in the mornings and evenings, as shown in figure 5-1 above. This trend is similar to that established by Pushkarev (1975) in his pedestrian studies (See Section 2.4). Consequently, the pedestrian walkway width should be designed using the maximum flow of 0.49 pedestrians/second.



Source: Author, November, 2015

Figure 5–2: Density – Speed relations comparison

Figure 5-2 above shows that as volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream. All the four trends above show a similar pattern. It is evident that the findings of Navin et al (1969), Older (1968) and Fruin (1987) concerning maximum pedestrian flow are in very close agreement, though the speeds differ. These extreme flow rates are very high and begin to come somewhat close to those attainable in highly organized military formations. The trend from the Author's (2015) population in *Komarock* Area is slightly different, with higher speeds and lower densities. One may speculate that this may be due to the lower pedestrian numbers within the study area resulting in lower flows as compared to the forced downtown flows highlighted by Older (1968), Oeding (1963), and Fruin (1987).

5.2 PEDESTRIAN CROSSING SPEEDS

The data collected was analysed to obtain crossing speeds of various pedestrian categories in different circumstances. Various statistical aspects of the speed were determined such as minimum, mean, 85th percentile and maximum. Further the standard deviation and the 95% confidence intervals were also determined. A summary of the pedestrian crossing speeds is presented in Table 5-4 below.

Table 5–4: Pedestrian Crossing Speed Parameters

Type of Pedestrian	N	%	Crossing Speeds in Meters per Second				Standard Deviation	95% C. I
			Minimum	Mean	85th Percentile	Maximum		
Males	464	47.6	0.407	1.447	1.983	6.133	0.881	0.006
Females	422	43.3	0.232	1.459	2.049	3.983	0.697	0.005
School Going Age	65	6.7	0.562	1.206	1.633	1.822	0.487	0.009
The Old	59	6.1	0.524	1.325	1.707	3.538	0.883	0.018
Groups Population	48	4.9	0.139	1.002	1.570	2.674	0.650	0.011
Obstructed Pedestrians	172	17.6	0.139	1.064	2.009	3.187	0.813	0.009
With Luggage	404	41.4	0.374	1.336	1.935	3.983	0.724	0.006
Overall Population	**975**	**100**	**0.139**	**1.411**	**1.960**	**6.133**	**0.793**	**0.004**

Researcher's Analysis (N= 975)

Source: Author, November, 2015

Table 5-4 above shows that the average crossing speed of the study area was approximately 1.41m/s which is almost similar to the HCM (2010) recommended value of 1.40m/s. Optimum crossing speeds by pedestrians are less likely to result in accidents. Mean crossing speeds for the elderly (above 60years old) were noted to be 1.32m/s, which are slightly above the HCM (2010) recommended speed of 1.20m/s. This may be due to the fact that pedestrians tend to cross the road much faster in order to avoid being hit by oncoming motorised traffic especially in areas without pedestrian crossings or pedestrian signals.

5.3 PEDESTRIAN ELLIPSE AND SPACE CHARACTERISTICS

Pedestrian ellipse measurements are done in order to establish the suitable area that a pedestrian body ellipse can occupy at any given point. This in turn is used to help determine the minimum space standards suitable pedestrian space along a walkway. A summary of the results obtained is as shown in Table 5-5.

Table 5–5: Summary of Pedestrian Ellipse Characteristics

Measurement	Kayole Junction			Mama Lucy Hospital			Aggregate		
	L (m)	W (m)	Area (m^2)	L (m)	W (m)	Area (m^2)	L (m)	W (m)	Area (m^2)
Mean	0.597	0.406	0.242	0.588	0.376	0.221	0.593	0.391	0.232
Maximum	4.400	1.000	4.400	4.300	0.790	3.397	4.350	0.895	3.893
Minimum	0.300	0.180	0.054	0.280	0.120	0.034	0.290	0.150	0.044

Source: Author, November, 2015

HCM, 2010 recommends a simplified body ellipse of 0.45m by 0.61m (0.27m^2) as the basic space for a single standing pedestrian. Similarly, an area of 0.74m^2 is used as the buffer zone in evaluating a pedestrian facility. The situation within the study area is unique because of the extraordinary large goods such as doors, timber pieces, metal bars and boxes carried along streets and walkways by pedestrians. From the above study, the maximum pedestrian area required is 4.40m^2 while the minimum is 0.28m^2 considering the size of goods carried. This is however not practical because if each pedestrian were to occupy 4.40m^2, the pedestrian walkway would be excessively wide leaving no space to accommodate other elements of the road corridor. A mean of the areas, 0.24m^2 is therefore recommended as the adequate basic space for a single pedestrian.

5.4 EFFECTIVE WALKWAY WIDTH AND PEDESTRIAN LEVEL OF SERVICE

Quality levels were assigned to the various sidewalks based on the performance measures like speed, density, flow and effective walkway width. The results obtained were as shown in Table 5-6 below:

Table 5–6: Pedestrian Level of Service

Location	Weekday					
	Peak*		Effective width	speed	Flow rate (V_p)	Level of Service
	Time	Flow	(m)	(m/s)		
Mama Lucy	0630-0645	199	2.10	1.58	6.32	A
Kayole Junction	1900-1915	715	0.40	1.05	119.17	F
Masimba Junction	0630-0645	378	1.50	1.47	16.80	B
Komarock	0715-0730	205	1.50	1.51	9.11	B

** - Design for maximum flow rate*

Source: Author, November, 2015

For *Kayole* Junction Section with peak flow of 715 pedestrians every 15 minutes to achieve minimum PLOS B (23ped/min/m), the following effective walkway width needs to be effected.

$$V_p = V_{15}/ (15xW_e), \quad 23 = 715/ (15xW_e)$$

$$W_e = 2.0m$$

The Highway Capacity Manual (2010), recommends that each pedestrian should have at least 0.76m of effective walkway width to avoid interference when two pedestrians pass each other. However, from the above analysis, and to reach a convenient level of service A, the space requirement should be at least 1.50m per pedestrian. Similarly, from the above it is noted that

Komarock has a level of service B, Mama Lucy, A, *Kayole* Spine Road, F and Masimba B. Any level of service above B is considered adequate for the area as there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians and to avoid crossing conflicts. It should also be noted that portions of the walkway along *Komarock* and *Kayole* Spine Road had obstacles on them thereby reducing the effective width. A wider effective walkway width would have resulted in Level of Service A.

Along *Kayole* Junction, the Level of Service F is brought about by reduced effective walkway width as a result of obstacles being on the walkway. The general walking speed of pedestrians along this area is also below the recommended 1.52m/s. From the analysis, a minimum effective walkway width of 2.00m is sufficient to achieve the minimum pedestrian walking speed of 1.52m/s and flow rate of 23ped/min/m. This should therefore be applied all through the walkways especially along residential areas and where space allows.

5.5 EFFECT OF INCREASED POPULATION ON WALKWAY WIDTH

From the Table 5-7, an effective walkway width of 3.30m is required in order to accommodate pedestrian movement after population projection in year 2019. A wider width is required to cater for the numerous pedestrians returning home from work in the evenings (19.00-19.15). A width of 3.30m will allow a minimum level of service of B to be achieved within the next 5 years. A quick look at the area shows that there is sufficient space to allow for expansion of the pedestrian walkway.

Table 5–7: Optimum Effective Walkway after Population Projection (2019)

Location	Time	Weekday														
		2015			2016			2017			2018			2019		
		V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e	V_{15}	V_p	W_e
Mama Lucy	19.30-19.45	116	16	0.5	119	16	0.5	122	16	0.5	126	16	0.5	129	16	0.5
Kayole Junction	19.00-19.15	371	16	1.5	381	16	1.6	391	16	1.6	402	16	1.7	413	16	1.7
Masimba Junction	18.15-18.30	238	16	1.0	244	16	1.0	251	16	1.0	258	16	1.1	265	16	1.1
Komarock	15.15-15.30	128	16	0.5	131	16	0.5	135	16	0.6	139	16	0.6	142	16	0.6
Mama Lucy	06.30-06.45	199	16	0.8	204	16	0.9	210	16	0.9	216	16	0.9	221	16	0.9
Kayole Junction	18.30-18.45	565	16	2.4	580	16	2.4	596	16	2.5	612	16	2.6	629	16	2.6
Masimba Junction	06.30-06.45	293	16	1.2	301	16	1.3	309	16	1.3	317	16	1.3	326	16	1.4
Komarock	07.15-07.30	205	16	0.9	211	16	0.9	216	16	0.9	222	16	0.9	228	16	1.0
Mama Lucy	08.00-08.15	95	16	0.4	98	16	0.4	100	16	0.4	103	16	0.4	106	16	0.4
Kayole Junction	17.30-17.45	361	16	1.5	371	16	1.5	381	16	1.6	391	16	1.6	402	16	1.7
Mama Lucy	07.30-07.45	172	16	0.7	177	16	0.7	181	16	0.8	186	16	0.8	191	16	0.8
Kayole Junction	19.00-19.15	715	16	3.0	734	16	3.1	754	16	3.1	774	16	3.2	795	16	3.3

Source: Author, November, 2015

Walkway widths of 3.30m will definitely result in pedestrian walking speeds greater than 1.52m/s due to free flow thereby resulting in PLOS A.

5.6 ORIGIN AND DESTINATION STUDIES

From the analysis, it emerged that majority of the pedestrian trips were either home – work or home – school (See Figure 5-3). Adult males made the most work-based trips while children made the most school-based trips. This illustrates that the area is mainly residential hence the need for adequate pedestrian walkways to accommodate the high percentage of pedestrians.

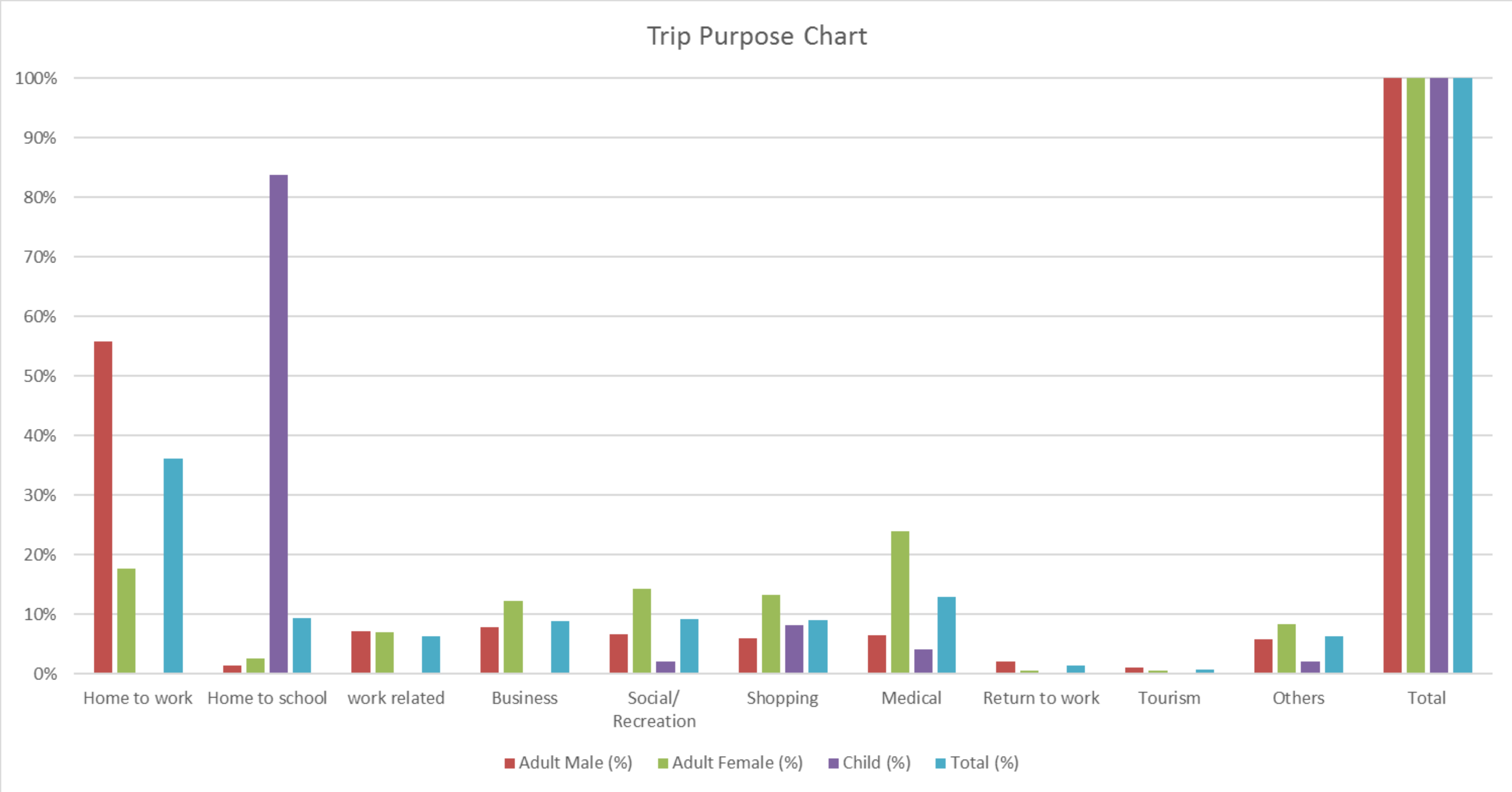


Figure 5–3: Trip Purpose Graph

Source: Author, November, 2015

5.7 COMPARISON OF DESIGN CRITERIA

A comparison of local design criteria was made against the criterion established from previous pedestrian capacity analyses carried out both locally and globally (See Table 5-8). This was important in order to determine whether to adopt the new local criteria developed or to continue with the generally worldwide acceptable criteria.

Table 5–8: Comparison of Design Standards and Criteria

Parameter	Recommended Criteria from Different Studies						
	Author (2015)	HCM (2010)	TFL (2010)	Australia (2009)	New Zealand (2015)	Mbeche (2001)	Fruin (1987)
Walking Speed (m/s)	1.26	1.52	1.33	1.20	1.50	1.02 - 1.20 (1.11*)	1.34
Min. Effective Walkway Width (for LOS A) (m)	2.00	1.50	1.50	1.20 – 2.40 (1.80*)	1.80	-	1.50
Crossing Speeds (m/s)	1.41	1.40	1.30	1.42	1.40	1.02 - 1.20 (1.11*)	-
Body Ellipse (m^2)/Area	0.24	0.27	0.27	0.21	0.27	0.30	0.46

Source: Author, November, 2015

** - Average value*

From table 5-8 above, the walking speed in *Komarock* (1.26m/s) is between the lowest value of 1.11m/s as established by Mbeche et al (2001) and highest value of 1.52m/s as established by HCM (2010). The HCM (2010) value has therefore been adopted as the recommended walking speed for design of walkways in *Komarock* Area. The minimum effective walkway width to achieve PLOS A in *Komarock* is 2.00m which is higher than the New Zealand (2015) recommended value of 1.80m and HCM (2010) value of 1.50m. The value of 2.00m has therefore been adopted as it would be sufficient to accommodate high pedestrian flows during peak periods.

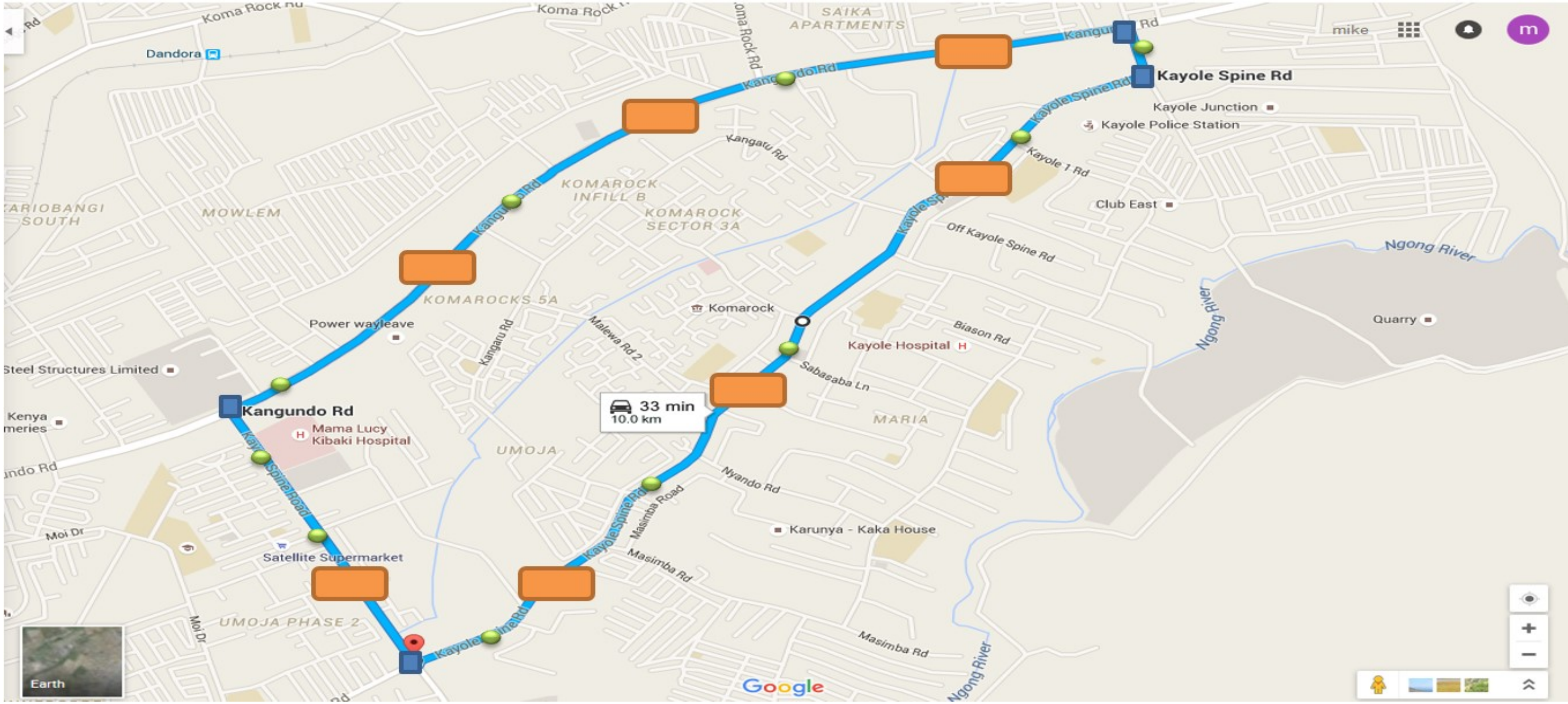
Pedestrian crossing speeds in *Komarock* is 1.41m/s which is generally similar to those obtained from other studies such as 1.40m/s from HCM (2010) and 1.42m/s from Australia (2011). A crossing speed of 1.41m/s has therefore been adopted as the recommended crossing speed in *Komarock* Area. The area covered by a single pedestrian in *Komarock* is $0.24m^2$ which is considerably lower than $0.46m^2$ recommended by Fruin (1987) but similar to the HCM (2010) recommended value of $0.27m^2$. From the analysis carried out in Chapter 5.3, $0.46m^2$ as recommended by Fruin (1987) has been found to be excessive for a single pedestrian and therefore $0.24m^2$ as calculated from the data obtained within *Komarock* has been adopted in the design of pedestrian walkways in *Komarock* Area. Table 5-9 below summarises the criteria to be adopted in pedestrian walkway design in *Komarock* Area:

Table 5–9: Criteria of Design Standards Recommended for Adoption

Parameter	Recommended Criteria for Adoption	
	Value	Comment
Walking Speed (m/s)	1.52	Adopted from HCM (2010)
Min. Effective Walkway Width (for LOS A) (m)	2.00	Recommended by Author (2015)
Crossing Speeds (m/s)	1.41	Recommended by Author (2015)
Body Ellipse (m^2)/Area	0.24	Recommended by Author (2015)

Source: Author, November, 2015

A pictorial representation of the proposed improvements toward the planning and design of pedestrian facilities along urban roads in *Komarock* is illustrated in figure 5-4:



- Raised pedestrian crossing with actuated pedestrian signals
- Pedestrian walkway redesigned to 2.0m width with improved covered drains along the entire corridor.
- Area with raised kerbs and 1.0m high steel railings
- Proposed bus bay locations

Figure 5–4: Proposed Improvements

Source: Author, 2015

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the key findings of this study, giving rise to policy recommendations and future considerations. It also examines the research study objectives and determines whether or not they have been met. The main objective of the study was to evaluate the pedestrian flow characteristics at *Komarock* Area in Nairobi County. An assessment of the operational performance of the pedestrian facilities, and the establishment of local pedestrian flow parameters, has been used as a foundation for modifying the existing design criteria of pedestrian walkways along urban roads in Kenya.

6.1 KEY FINDINGS

6.1.1 Objective One: To Establish the Challenges Facing Pedestrians along the Study Area

This study pointed out the shortcomings in the existing pedestrian infrastructure and also established the preferences of pedestrians for safe and comfortable walking. The provision of proper designated pedestrian crossing points near Mama Lucy Hospital, segregated continuous and well-maintained pathways, which were free from gaping manholes and poor drainage systems is needed along the entire study area. Evidently, the concerns about personal security were also an important factor in addition to the need to provide good quality infrastructure for all pedestrians, including those with disabilities.

In addition, the pedestrian walkways along *Kayole* Spine Road, *Masimba, Kangaru* and *Komarock* need to be designed with adequate width for people to move comfortably and raised adequately from the vehicular road surface, in order to enhance the safety of pedestrians. There is a need to design well-connected sidewalks throughout the study area, with ample bus bays, so that public transport will not stop on the road to pick up passengers in undesignated areas, thus interfering with pedestrian movement. The study further established that the capacities of the pedestrian walkways were not adequate for the peak flows. It is also evident from the assessment of pedestrian infrastructure and pedestrian interview surveys that efforts are required to keep the pedestrian platforms free from any physical obstructions, encroachment by hawkers and parking of motorized vehicles. Appropriate independent lighting needs to be designed for pedestrians along with street lighting for vehicular traffic as the lighting requirements for pedestrian and vehicular traffic are quite different.

6.1.2 Objective Two: To Determine the Adequacy of the Pedestrian Space, Flow and Density Conditions on the Walkways

The study established the pedestrian flow parameters for the study area, which included; speeds, flow rate, effective walkway width and PLOS. Further, the study observed that the speed-density relationships were linear as per the Greenshield Model, with lower densities obtained for higher speeds and higher densities obtained for lower speeds. Areas such as *Kayole* experienced PLOS "F" because of the reduced walkway width and high pedestrian flow rates in the morning. Others such as *Masimba* had PLOS "B." The study established that the adequate effective walkway width required to achieve PLOS "A" was 2.00m, with an average walking speed of 1.52m/s, and resulting in a recommended pedestrian flow rate of 23ped/min/m.

6.1.3 To Establish Ways of Addressing the Design Shortfalls of Pedestrian Facilities Along the Study Area.

Based on the research findings, the following parameters were established as guidelines towards the planning and design of pedestrian facilities along urban roads in *Komarock*:

- 1.52m/s is the minimum pedestrian speed to be used during design of a pedestrian walkway.

- The minimum effective walkway width to achieve Level of Service B along a pedestrian walkway is 2.00m. This will also accommodate wheelchair traffic especially around Mama Lucy Hospital, which requires an effective walkway width of 1.80m.

- As the volume and density of pedestrians' increases, the pedestrian speed declines because of closer interactions among pedestrians. This is common especially in the mornings and evenings, which are considered peak pedestrian movement periods.

- The average pedestrian crossing speed is approximately 1.40m/s, which is similar to the minimum recommended value of 1.41m/s.

- An average pedestrian space of 0.24m^2 is considered adequate, for a single pedestrian.

6.2 RECOMMENDATIONS

This study underscores the significance of planning and providing pedestrian facilities in accordance to the observed pedestrian behaviour and needs, rather than relying on specifications and findings from the cities with dissimilar characteristics. Based on the quantitative measures of pedestrian flow, walking speed, and flow density, as well as additional environmental factors that contribute to the walking experience along urban roads in *Komarock*, this study recommends the following:

- Redesign of the pedestrian walkway along *Kayole* Junction to the recommended 2.0m width, which can also accommodate disabled movement (See Figure 6-1).

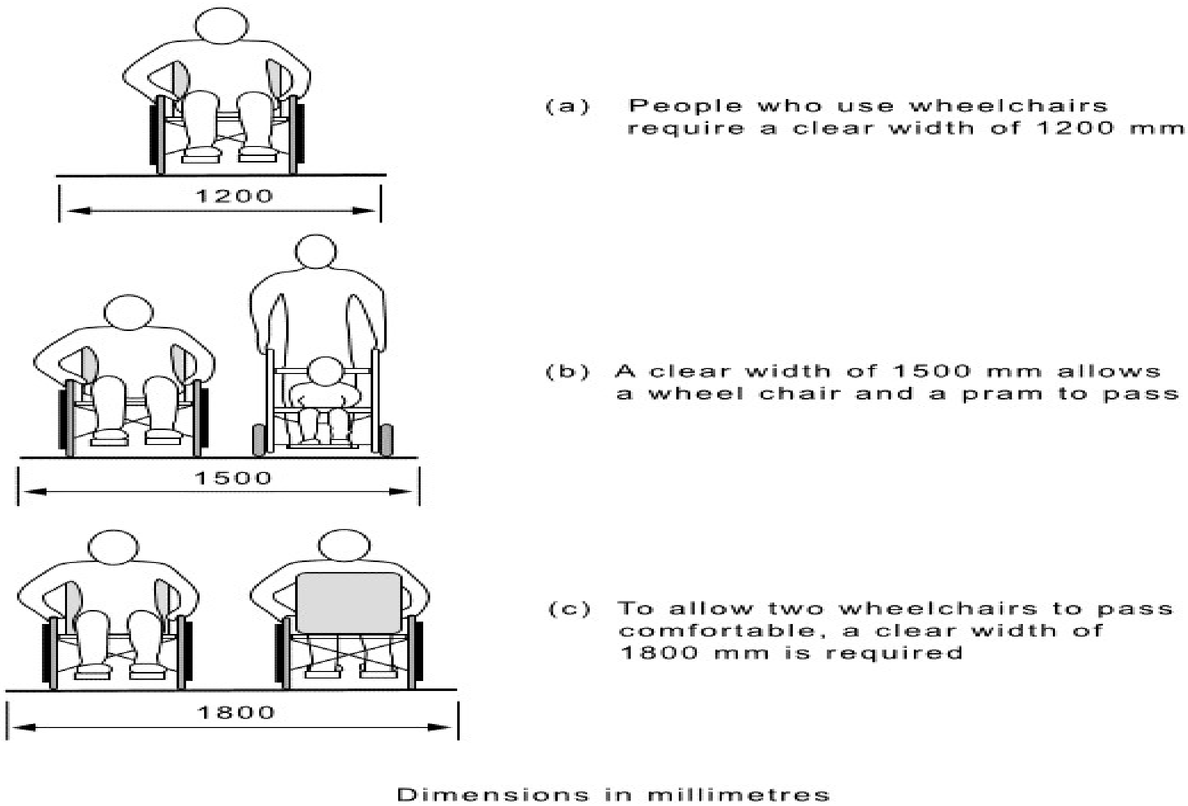


Figure 6–1: Minimum Clear Widths

Source: New Zealand Standards, Design for Access and Mobility, 1994

- The installation of raised pedestrian crossing humps along *Kayole* Junction, *Masimba* and Mama Lucy Junction to reduce vehicular speeds. This would allow pedestrians to cross the road as illustrated in Figure 6-2 below:

Figure 6–2: Raised crosswalk at an intersection in Malmö, Sweden.

Source: Pedestrian Safety and Mobility in Europe, 2010

- The installation of actuated pedestrian signs and ramps for the disabled, to allow pedestrians to access Mama Lucy Hospital as illustrated in Figure 6-3 below:

Figure 6–3: Near-side pedestrian signal with confirmation light in Bristol, UK

Source: Pedestrian Safety and Mobility in Europe, 2010

- Installation of raised kerbs and 1.0m high railings along the entire study area to allow for the segregation of motorised and non-motorised transport (See Figure 6-4).

Figure 6–4: Railing used to direct pedestrians to crossing locations in London, UK

Source: Pedestrian Safety and Mobility in Europe, 2010

- The demolition of structures occupying part of the walkway width and enforcement of laws regarding encroachment, in order to keep the pedestrian walkways free from encumbrances. City streets may also be converted to accommodate pedestrians as illustrated in Figure 6-5 below.

Figure 6–5: Before-and-after photos of Strøget in Copenhagen.

Source: Pedestrian Safety and Mobility in Europe, 2010

- Installation of road signs designating pedestrian zones at *Masimba*, Car Wash, Mama Lucy and *Kangundo* Sections as illustrated in Figure 6-6 below:

Figure 6–6: Speed reducers and road signs

Source; New York City Dept. of Transportation, 2010

- The identification of a designated parcel of land where a dedicated parking lot for vehicles can be put up along the study area. This will prevent them from parking on the pedestrian walkways and streets;

- The implementation of a policy on management of motor cycles within the country, thereby creating law and order by providing them with designated cycling and parking areas;

- Improvement of drains and drainage along the entire study area to control flooding (See Figure 6-7 below).

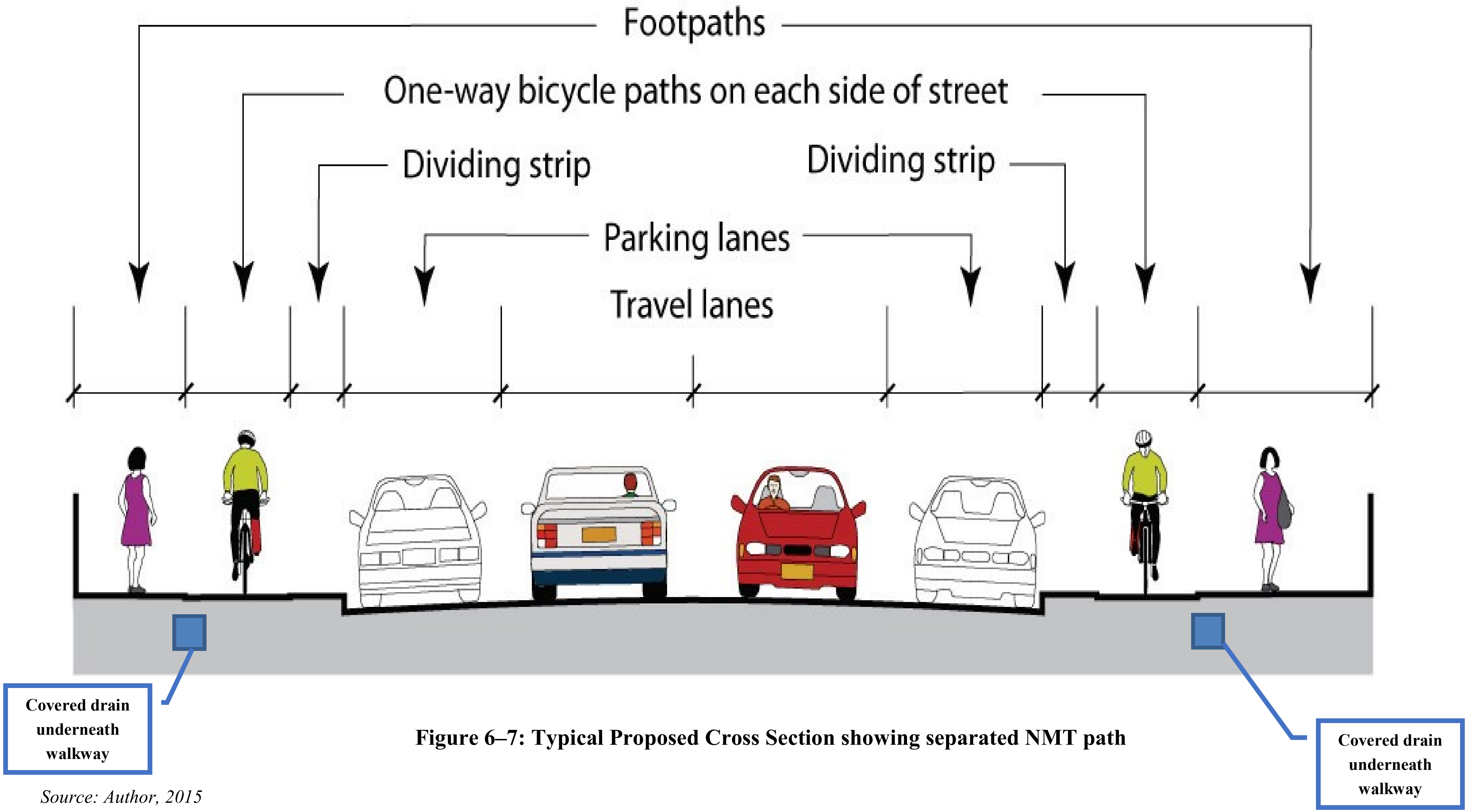


Figure 6–7: Typical Proposed Cross Section showing separated NMT path

Source: Author, 2015

- The installation of standard bus bays along the study corridor to replace the makeshift ones and prevent haphazard stopping by public transport vehicles such as matatus.

- The Junction improvement at Mama Lucy Hospital and *Kangundo* Road by use of staggered pedestrian crossings located at right angles. The most important design feature is that the offset forces pedestrians to walk longitudinally in the median for a short distance so they face oncoming traffic (See Figure 6-8 below).

Figure 6–8: Offset pedestrian crossing at a signalized intersection in Bristol, UK.

Source: Pedestrian Safety and Mobility in Europe, 2010

Finally, the study recommends further research into pedestrian flow characteristics along urban roads in Kenya, with an emphasis towards shared pedestrian facilities and travel time modelling in order to assist in developing local design criteria for the Kenyan scenario.

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APPENDIX

APPENDIX 1: PEDESTRIAN INTERVIEW QUESTIONAIRE

Date:……………………………

Location………………………..Name of Respondent:……………………………………

Tel:..Nationality:………………………………………………

Sex:……………………………Occupation/Designation:……………………………………

(a) Route from (*Only fill part (ii) to (iv) if pedestrian uses multiple routes*)

(i) ………………………….to…………………………….

(ii) ………………………….to…………………………….

(iii) ………………………….to…………………………….

(iv) ………………………….to…………………………….

(b) How often do you make such trips?

(i) Everyday

(ii) 4-6 times a week

(iii) 1-3 times a week

(iv) Occasionally

(v) Once in a while

(c) Why do you prefer this route?

(i) It is shorter

(ii) The route condition is better

(iii) It is more secure

(iv) I do not know

(d) Which alternative routes are available to you?

(i) ………………………….to…………………………….

(ii) ………………………….to…………………………….

(iii) ………………………….to…………………………….

(iv) ………………………….to…………………………….

(e) Do you have access to alternate means of transport?

(i) Yes (*Answer question (f)*)

(ii) No

(iii) I do not know

(f) Why do not you use your alternate means of transport?

(i) It is expensive

(ii) It is cumbersome to use

(iii) I do not know

(iv) Any other reason. (*Please state*)…………………………………………………

(g) How can pedestrian movement along the study corridor be improved?

(i) (*Please state*)…………………………………………………………………..

APPENDIX 2: PEDESTRIAN COUNTER INSTRUCTIONS

1) Day and Dates: These should be clear enough.

2) Time(s): Weekday: 4.00am – 9.00pm, Weekend: 4.00am – 9.00pm

3) Count Supervisor Name: ____________________ Phone No.__________________________

4) Enclosures: You should have the following in this packet:

a) a map showing your count location

b) a count form

c) a box file or an envelope to store the completed forms

5) Other Items Needed: Please make sure to bring:

a) a pen / pencil

b) Something to write on (clipboard, portfolio, etc.)

c) some sort of timekeeping device (cell phone, watch)

d) weather-appropriate clothing, water

6) Introduction: This is a routine count taken throughout the Kangundo Road, Kayole Spine Road and Kangaru Road Corridors. Data collected from these counts will be used to monitor pedestrian movement characteristics along the study corridor.

7) Assignments: Each location will have at least one counter. Depending on the number of counters, some locations may have more than one counter. In these cases, please use only one count form per location. Since the locations with multiple counters are expected to be busier, it will work best if one person counts and the other person fill out the forms.

8) Conducting the Count: You have been provided with one copy of the count form. Please, make sure to coordinate the correct time period with the correct box. Also, please make sure to write your name and location on each form.

9) The count itself is very simple: place a hatch mark on the form for each passing pedestrian. People in wheelchairs are to be counted as pedestrians while people walking their bicycles should be counted as cyclists.

10) Returning the Count Forms: Please submit to..

ATTN: ....

11) Other Information: The accuracy of the count depends largely on the coverage of all points during the entire morning and evening commute. Please make sure to get your location 15 minutes or more ahead of count time!

If you have any problems or know that you won't be able to make it, please call your count supervisor ASAP (see top for phone numbers). They or one of their colleagues will be coming around to check on you during the counts.

APPENDIX 3: PEDESTRIAN VOLUME COUNT FORM

PEDESTRIAN VOLUME SHEET		
LOCATION ID:		
REGION:	HIGHWAY:	TYPE OF CONTROL:
DATE:	TIME: FROM TO	OBSERVER:
REMARKS:		

to WEST	to EAST
Distance………metres	
Raised Median:Yes/No	

to SOUTH

to SOUTH

Distance………metres

Raised Median:Yes/No

Distance………metres

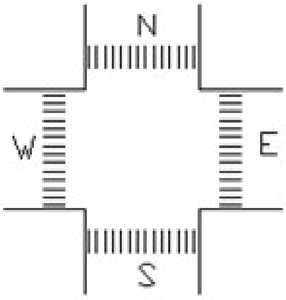
Raised Median:Yes/No

to NORTH

to NORTH

to WEST	to EAST
Distance………metres	
Raised Median:Yes/No	

APPENDIX 4: SUMMARY OF PEDESTRIAN MOVEMENTS

SUMMARY OF PEDESTRIAN MOVEMENTS		
LOCATION ID:		
REGION:	HIGHWAY:	
OBSERVER:	DATE:	
	WEATHER:	
	ROADWAY WIDTH(METRES):	
	N/S:	E/W:
	MEDIAN WIDTH(METRES):	
	≥1.2METRES	<1.2METRES
	REMARKS:	

PEDESTRIAN MOVEMENTS

15-MINUTE TIME PERIOD	NORTH LEG		SOUTH LEG		EAST LEG		WEST LEG	
	N/E	N/W	S/E	S/W	E/N	E/S	W/N	W/S
TOTAL LEG								

STREET NAME NORTH TO SOUTH:	TOTAL NORTH LEG+TOTAL SOUTH LEG:
STREET NAME EAST TO WEST:	TOTAL EAST LEG+TOTAL WET LEG:

APPENDIX 5: PEDESTRIAN GROUP SIZE STUDY FORM

PEDESTRIAN GROUP SIZE STUDY					
LOCATION ID:					
REGION:			HIGHWAY:		
STUDY DATE:	TIME: FROM: AM/PM		TO: AM/PM	OBSERVER:	
CROSSWALK ACROSS:			CURB TO CURB DISTANCE(W):		
RAISED MEDIAN: YES		NO	WIDTH OF MEDIAN:		
REMARKS:					

GROUP SIZE	NUMBER OF GROUPS		NO. OF ROWS(N)	CUMULATIVE TOTAL	COMPUTATIONS
	TALLY	TOTAL			
5 or less					
6 to 10					
11 to 15					
16 to 20					
21 to 25					
26 to 30					
31 to 35					
36 to 40					
41 to 45					
46 to 50					
Total Number of Groups					

Calculation of adequate gap time(G) in seconds:

G = W/3.5 + 3+ (N-1)2

Where W = Width of roadway in metre

3.5 = Assumed walking speed in metre/second

3 = Perception and reaction time in seconds

(N-1)2 = Pedestrian clearance time

N = Number of rows in 85th percentile group size

2 = Time interval between rows in seconds

APPENDIX 6: ORIGIN & DESTINATION STUDY FORM

SURVEY DATE		PEDESTRIAN ORIGIN - DESTINATION SURVEY FORM			SHEET NO.	
SURVEY LOCATION		Interviewer			HOUR ENDING	

PEDESTRIAN TYPE.	WHERE DID THIS TRIP BEGIN	ESTABLISH TYPE AT ORIGIN	WHERE WILL THIS TRIP END	ESTABLISH TYPE AT DESTINATION	STOP OVER LOCATION	TRIP PURPOSE	NUMBER OF PERSONS IN THE PLATOON	GOODS CARRIED (Y/N)	GOODS CARRIED BY VOLUME FILLED (CIRCLE)	COMMODITY CARRIED	CHANGE IN MODE EXPECTED (Y/N)
									¼ ½ ¾ 1.0		
									¼ ½ ¾ 1.0		
									¼ ½ ¾ 1.0		
									¼ ½ ¾ 1.0		
									¼ ½ ¾ 1.0		

PEDESTRIAN TYPE

1. Adult Male
2. Adult Female
3. Child

ESTABLISH TYPE

1. Residential
2. Farm
3. Factory
4. Education
5. Hospital
6. Terminal
7. Wholesale
8. Construction site
9. Retail shop/ market
10. Warehouse
11. Harbour
12. Others

TRIP PURPOSE

1. Home to work
2. Home to school
3. Work related
4. Business (Trading)
5. Return to Company
6. Social /Recreation
7. Tourism (Game park/ sight- seeing)
8. Shopping (buying)
9. Medical (hospital)
10. Other (to be specified)

MAIN COMMODITY

1. Food crop (maize, rice, wheat) etc.
2. Cash crop (coffee, tea, etc)
3. Perishable (fish, milk, fruit, Vegetable etc.)
4. Const. Material (cement, stones, gravel, pipes)
5. Metal/ Machinery
6. Forestry products (timber, charcoal)
7. Fuels (any petroleum products)
8. Chemical product (fertilizer, paints)
9. Livestock (cows, goats, Carmel, etc)
10. Household retail products (Beverage, oil, sugar, salt, flour, etc)

APPENDIX 7: SAMPLE WALKWAY WIDTH MEASUREMENT FORM

WALKWAY WIDTH MEASUREMENT FORM							
ROAD NAME:							
CHAINAGE	**WIDTH (M)**		**CONDITION (PAVED/UNPAVED)**	**CHAINAGE**	**WIDTH (M)**		**CONDITION (PAVED/UNPAVED)**
	LEFT	**RIGHT**			**LEFT**	**RIGHT**	
0+000				**1+000**			
0+040				**1+040**			
0+080				**1+080**			
0+120				**1+120**			
0+160				**1+160**			
0+200				**1+200**			
0+240				**1+240**			
0+280				**1+280**			
0+320				**1+320**			
0+360				**1+360**			
0+400				**1+400**			
0+440				**1+440**			
0+480				**1+480**			
0+520				**1+520**			
0+560				**1+560**			
0+600				**1+600**			
0+640				**1+640**			